Industrial

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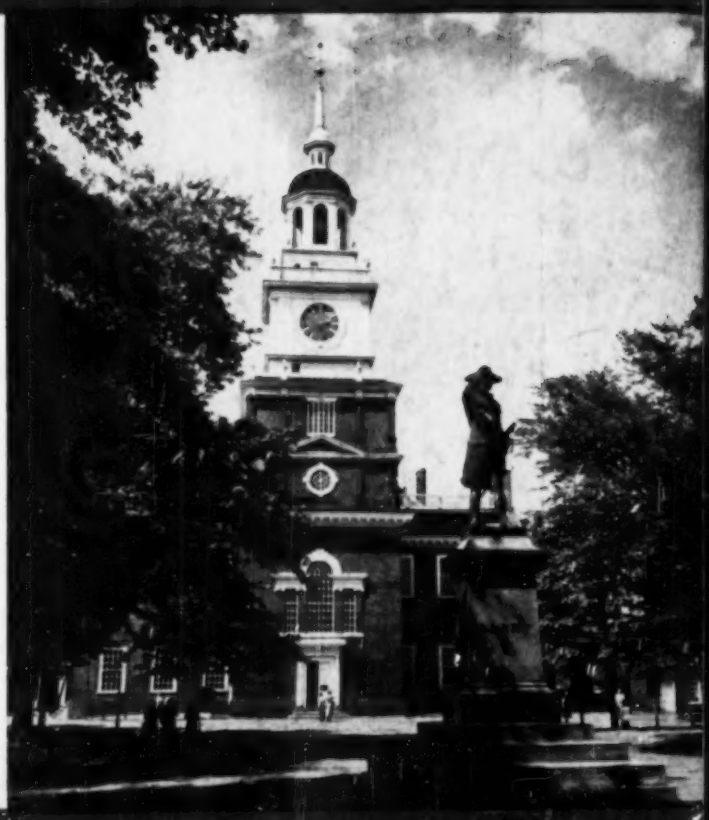

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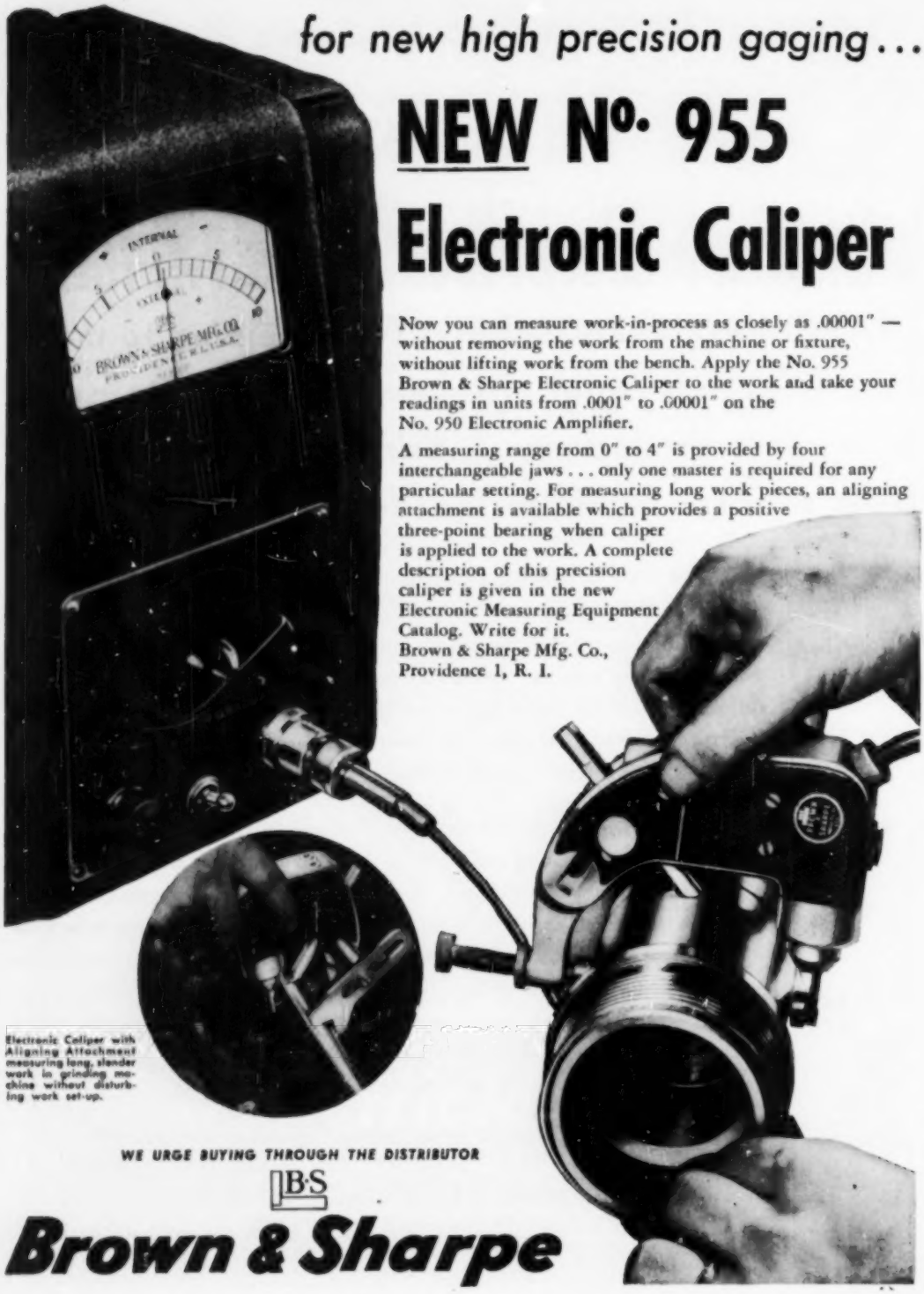

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Industrial Quality Control

Vol. IX **MAY, 1953** **No. 7**

Table of Contents

Janus ... 3
Managing Quality Control to Encourage Quality Mindedness
A. V. Feigenbaum ... 16
Installing a Quality Control System
J. M. Juran ... 21
The Technique of Preventing Defects
Leonard A. Seder ... 23
The Place of SQC in an Industrial Organization
Edwin G. Olds ... 30
Using Training Conferences as a Quality Control Catalyst
Paul C. Clifford ... 38
Statistical Cost Control in the Paper Industry
Carl E. Noble ... 42
Probability Statistics Applied to Tax Returns
A. C. Rosander ... 46
Control Charts May Be All Right, But—
Frank Proschan ... 56
Special Applications for Quality Control Charts
Wyatt H. Lewis ... 77
Note on the Use of Fixed Numbers of Defectives and Variable Sample Sizes in Sampling by Attributes
C. C. Craig ... 83
Vendor Certfication
M. E. King ... 86
Fundamental Principles of Sequential Analysis
Irving W. Burr ... 92
Quality Control at Timken-Detroit Axle Company
James Kaver, Sr. ... 102
The Statistical Approach to Bulk Sampling Problems
B. H. Lloyd ... 113
7th Annual ASQC Convention ... 65
ASQC National Officers ... 73
ASQC National Directors ... 74
ASQC Section Chairmen ... 75
Practical Aids
Ellis R. Ott, Editor ... 124
Problems Department
Paul C. Clifford, Editor ... 130
Bibliography
Joseph Moshin, Editor ... 134
Forthcoming Courses in Statistical Quality Control ... 138
Index of Advertisers ... 141, 142
American Society News ... 143
Classified Ads ... 144
Consulting Services ... 144

Industrial Quality Control is published bi-monthly by the American Society for Quality Control, Inc. Entered as second class matter September 18, 1950, at the Post Office at Milwaukee, Wisconsin. Yearly subscription $3.00; non-members $6.00. Office of publication, 239 East Chicago Street, Milwaukee, Wisconsin. Headquarters office, 70 East 45th Street, New York 17, N. Y.

JANUS

The first of January, as you know, is that time of the year when many of us indulge in the practice of making New Year's resolutions. Some of us, however don't even bother to make any on the theory that we will then have fewer resolutions to break next week. Those who do make them, on the other hand, are following a rather age-old custom which stems indirectly from the Roman god, Janus.

As most of you probably also know, this gentleman Janus was responsible for the guarding of doorways, portals, gateways and the like—a simple matter for him with his two faces which could watch in both of the directions to which the doorways gave access.

Ultimately, however, the Romans began to attach philosophical significance as well as physical importance to Janus' functions so that he was also "put in charge of" that month which represented the starting of a new year. This was a rather logical extension of his functions since it represented the guarding of a portal in time. Again his two faces played an important role because with them he was able to help people look backward and forward at the same time—backward over the failures and accomplishments of the year just past and forward over the hopes of the year coming up.

And this consequently is what the month of January has come to mean to most of us—a time to take time for review, a chance to examine past mistakes, an opportunity to lay plans for the future which we hope will be devoid of past errors.

The point in this discussion, of course, is that for ASQC the opportunity for looking over the past and new years is coming up with the conclusion of the fiscal year at the end of June. Each of us—as individuals, as sections, as a national group—should examine our accomplishments of the past year with pride, our ball-dropping with chagrin. We should look forward to new, greater efforts—efforts from which we eliminate the futile motions we went through before, efforts which we sincerely try to convert into great accomplishments. But most of all we should not lose sight of the fact that the greatness of an achievement is not judged on the basis of its massiveness.

Finally it should be pointed out that this idea of an "annual review" can be streamlined into a regular working habit so that one's *modus operandi* will incorporate a review of past experiences as a continual phase of current activity.

A particular problem, then, might be attacked with something like the following procedure: an analysis of the problem at hand with a reexamination of previous related problems to determine whether they would modify the analysis of the present one, carrying out the action called for by the problem, and finally a review of the analysis and action immediately upon completion and while the results are still fresh. This review would then be one of the things to be reexamined during the analysis of some future problem. It's also entirely probable that during the reexamination stage of the new problem, one's opinion about the review which was made at the conclusion of the previous problem may change. Both viewpoints—the review made while the problem was fresh and the reexamination mellowed by time—are desirable.

The notion which is significant here, though, is the point that our friend Janus should be an ever-present guardian—not merely an agent for one day or month of the year. To the same extent that statistical analysis increases the assurance that we will make correct decisions, so will the idea of a continuing review, analysis, action and review greatly increase the assurance that our efforts will result in solid achievement.

GRF

Our Cover courtesy of Philadelphia convention and visitors bureau.

Industrial Quality Control

Published Bi-monthly
by the

AMERICAN SOCIETY FOR QUALITY CONTROL, Inc.

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INDUSTRIAL QUALITY CONTROL is published in January, March, May, July, September, and November, and is mailed to all members of the Society as one of the privileges of membership.

Direct subscriptions to INDUSTRIAL QUALITY CONTROL are not accepted from individuals. However, subscriptions will be received from Libraries and like institutions at $6.00 per year. Remittances must be in United States funds and should be sent directly to the Executive Secretary of the Society.

Back issues, comprising Volumes I through VIII are available at $8.00 per volume, including the Index. Individual issues are $1.50 each.

Correspondence concerning institutional subscriptions, requests for back issues, and allied matters should be addressed to

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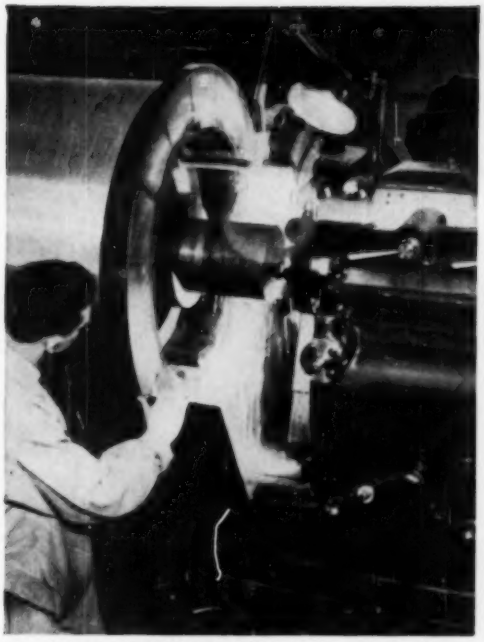

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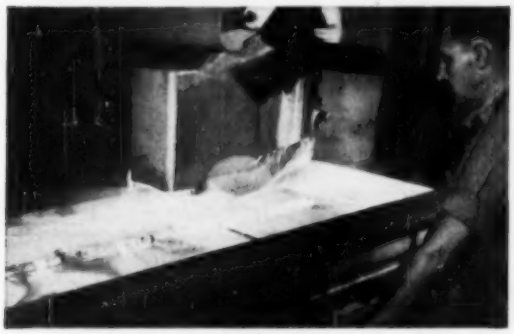

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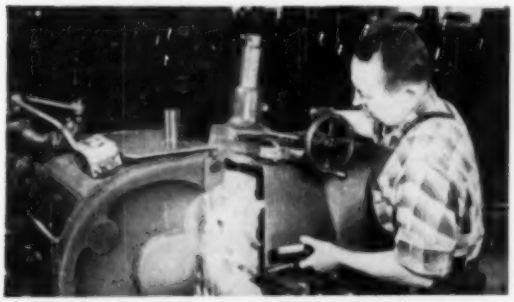

YOU CAN PROVE THE DIFFERENCE. From general purpose to high production work, every job you do with the new G Bond wheels will benefit by the unique cutting action that grinds faster, freer, and cooler.

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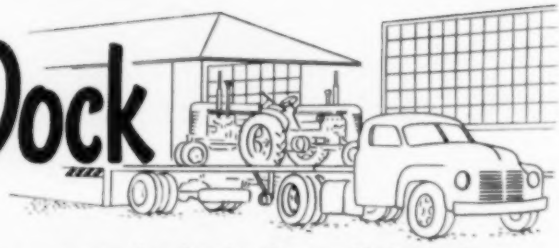

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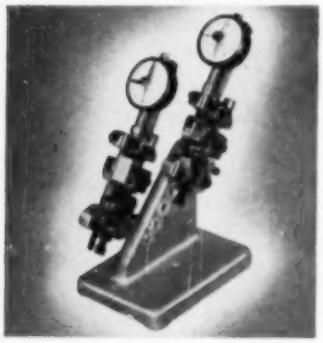

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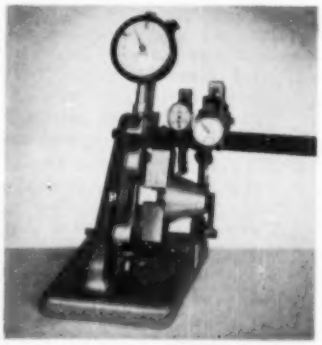

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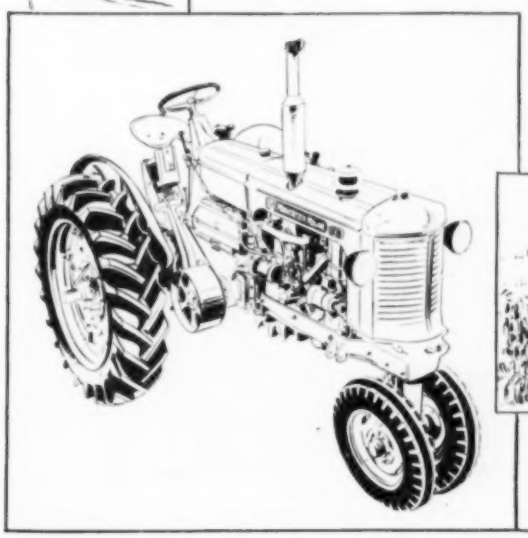
Hopkins Plant	1	21	51	95
Home Office	1	6	24	32
Como Plant	0	2	1	4
New Brighton Plant	0	0	0	2
Moline Plant	0	22	24	58
Louisville Plant	1	13	51	86
Divisions	1	8	11	36
Argentina	0	0	7	8
	4	90	277	533

TOTAL Old-Timers, Company-Wide—904 (active)



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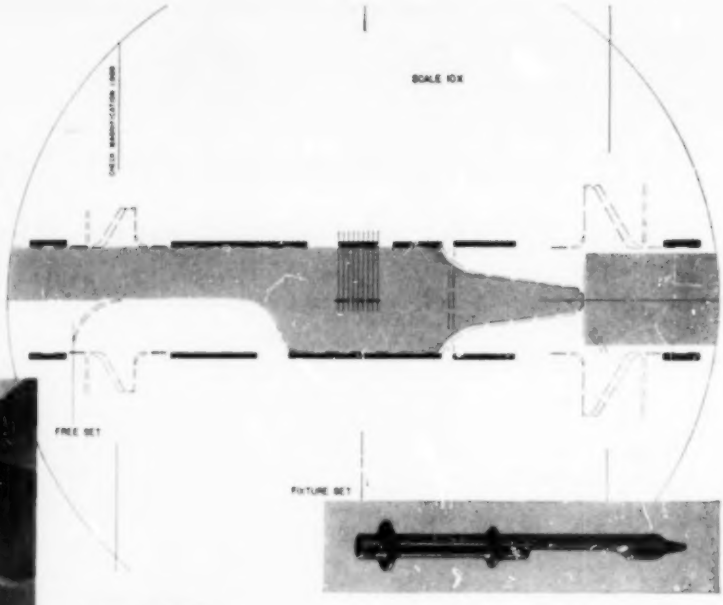
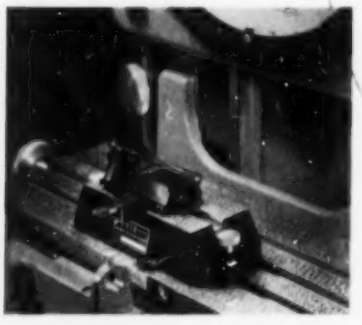
MINNEAPOLIS-MOLINE
MINNEAPOLIS 1, MINNESOTA

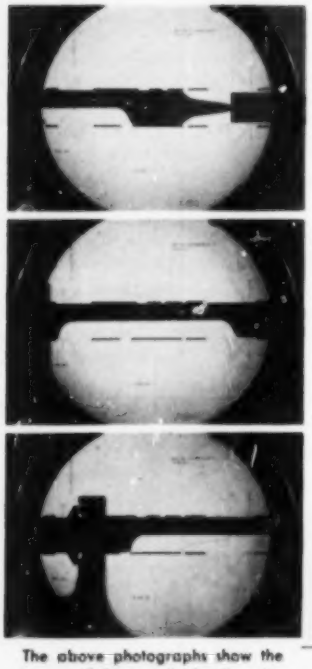
The heavy lines on the Chart-Gage have indentations forming slits of light when the part is within tolerance. If the part is undersized, light is seen under the entire line. If oversized, no light is seen. Only a quick glance is necessary to check tolerances. Experienced help is not required.





26 DIMENSIONS...

checked in 60 seconds



The above photographs show the image of the part in the three inspection positions. The same "composite" Chart-Gage is used for all three.

The firing pin illustrated above has 26 critical dimensions. Yet, by Optical Projection Gaging, the entire inspection takes less than 60 seconds—a fraction of the time and costs required with mechanical gages.

The part is mounted in a fixture on the stage of a Kodak Contour Projector. Its image, magnified 10 times, is projected on the screen and compared with a Chart-Gage. Although the image of the 3½" part is 35" in length, the entire part is checked on the 14" diameter screen by means of indexing the part in the fixture. The entire procedure requires less time than it would take to merely handle the gages ordinarily used.

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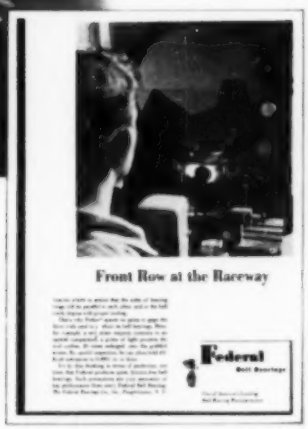

To see how a Kodak Contour Projector can help you reduce inspection costs, improve quality, send for our new 12-page booklet. It gives you details of both the Model 2A, for precision micrometry, and the Model 3, for fast, routine gaging. For your copy, write to:

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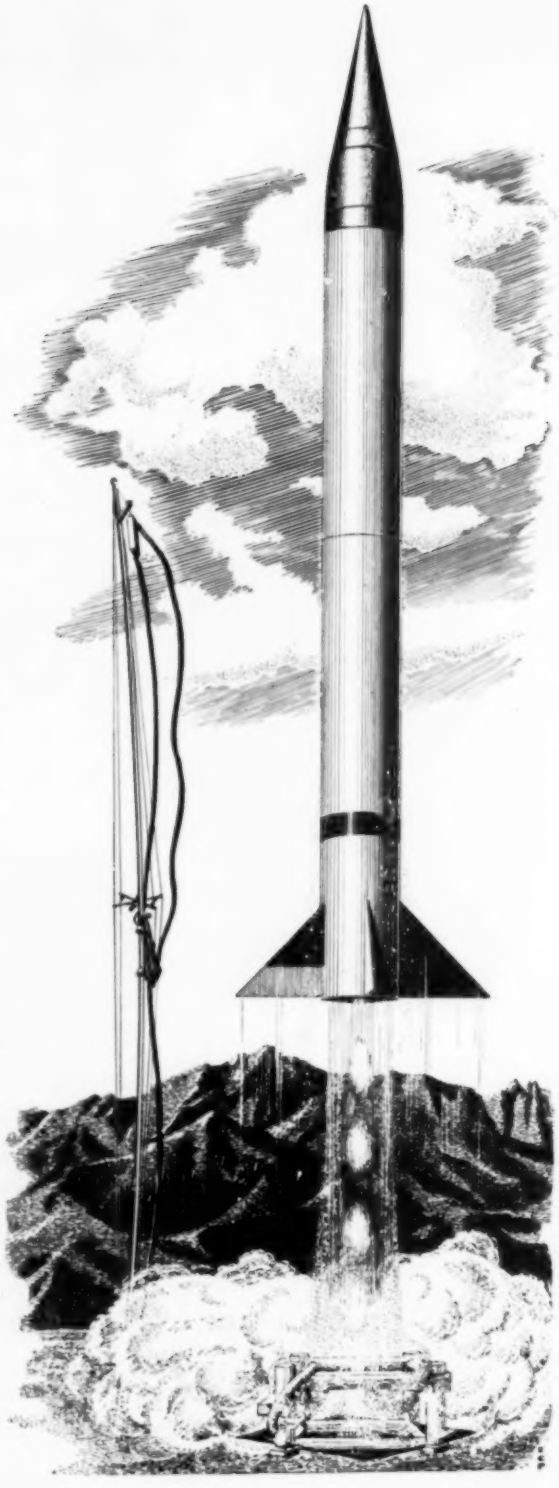

Pipes that grew without getting bigger

Cross-section of coaxial cable. To triple capacity, Bell Laboratories and Western Electric engineers had to make 1000 amplifiers work perfectly in tandem . . . feed repeater power along the same cable that carries messages . . . put signals on and off the line at numerous cities along the route without distortion.

Pencil-size pipes carry telephone messages and television across country through the Bell System's coaxial cable. Once, each pipe could carry 600 voices, or one television program. Now it can carry 1800 voices, or 600 voices *plus* a broadcast quality television program.

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The conversion expense is less than the cost of laying extra coaxial cables. But it calls for highly refined manufacturing procedures, made possible only by close co-operation of Bell Laboratories and Western Electric, manufacturing unit of the Bell System.

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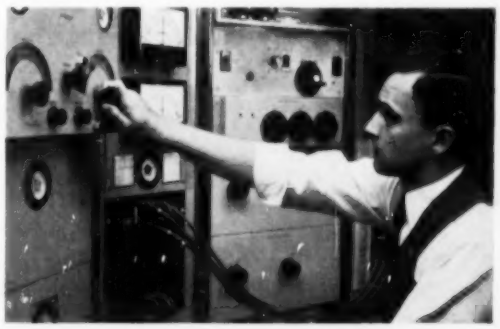

Laboratories engineer tests new triple-duty coaxial system. It marks the first time that telephone conversations and television can travel through the same pipes at the same time. With a wider frequency band being transmitted, big problem was to eliminate interference between the two types of signals.

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Managing Quality Control to Encourage Quality-Mindedness

A. V. FEIGENBAUM

General Electric Company, Lockland, Ohio

IN the final analysis, product quality depends upon conscientous people—upon sound, harmonious, skilled human effort. This human effort, in its turn, depends upon the very intangible but extremely important spirit of "quality-mindedness" extending from top management right through to the men and women at the bench. It is scarcely surprising that genuine success for a modern quality control program is directly related to the degree of this quality-mindedness that exists in a plant. Technical methods—no matter how important we can all agree they are—cannot alone assure any long-term effectiveness for a factory QC program.

The initial and greatest continuing objective in the management of modern programs, therefore, must be the establishment and maintenance of positive and conscientious attitudes among plant personnel toward quality and the modern means for its control. These attitudes will not automatically develop—nor be retained if they are already in existence—merely through the installation of a modern QC program. They must be deserved and earned—through action by plant top management and members of its QC organization, through the results gained from work in the quality control activities.

The remarks in this article are principally concerned with this process of earning quality-mindedness. They will attempt to review some of the considerations that are involved in so managing a modern QC program that positive quality attitudes may be earned to the fullest extent desirable.

QUALITY-MINDEDNESS AMONG PLANT PERSONNEL

Quality-mindedness—a spirit that you and I can sense when we study a factory even though we have not yet learned how to measure it quantitatively—relates to and may be fostered by many factors in a plant. The calibre of employee and labor relations effort, operator education, quality and slogan campaigns, the competence of supervision, quality training courses are all fully pertinent here.

But there is a factor whose impact on positive quality attitudes is more important than any of these. Most influential toward quality-mindedness has been the total impact on plant personnel's quality habits that results directly and indirectly, formally and informally, from the manner in which a factory QC program is introduced and organized during the first weeks and months it is being installed.

What, through deeds rather than words, does modern quality control really come to mean to the foreman, to the design engineer, to the sales engineer? Do they see it as a threat to their responsibilities, as a mystery, as an aid? What does quality control come to mean to cost accounting, in the laboratory, to packaging and shipping? What does quality control come to mean to top management of the plant?

Most important, what does quality control come to mean to the plant QC engineers themselves? Has the activity been so well organized that they can enthusiastically be at the center of eating, speaking, and breathing quality-mindedness? Or has the activity been so organized that the QC engineers become confused as to just what it is they are responsible for, so organized that they become frustrated and of little value as top-flight ambassadors for encouraging positive attitudes toward quality?*

Skilled students of human effort in industry have repeatedly told us that plant personnel's attitudes are determined not so much by the intent—no matter how sincere or sound—on the part of those managing a business method like quality control as they are influenced by what people themselves see in the method wherever they encounter it in their day-to-day work. How can we manage QC programs in such a fashion that plant personnel see, during the early months of the programs' installation, those elements which encourage positive thinking about product quality and its control?

TWO STEPS FOR ASSURING QUALITY-MINDEDNESS

There are, I believe, at least two essential steps that must be taken very early in the development of a QC program in order to help assure these positive quality attitudes for a plant.

Step One: To establish and maintain a definite human relations sequence for introducing the program in such a manner that it consciously and knowingly creates an environment in which quality-mindedness is encouraged among all plant personnel.

Step Two: To establish and maintain a pattern for organization of the QC program which makes it possible to achieve fast, reliable, modern, plant-wide quality results in a routine which emphasizes, and does not impair or destroy, quality responsibility and authority on the part of the foreman, the design engineer, the salesman, and the inspector.

Of these two steps, industrial experience seems to show that the first is easier of achievement than the second — that quality-mindedness falls by the wayside during the installation of a program more because of poor QC organization than because of poor introductory technique.

I should like to concentrate my remarks upon these two steps. I should like to discuss the first—sound over-all introduction of a Quality Control program—principally from the point of view of an intro-

*Certain sections of the material to follow are after the book, *Quality Control—Principles, Practice and Administration*; A. V. Feigenbaum, McGraw-Hill, 1951, 443 pages.

ductory sequence that industrial experience in several plants is coming to show as extremely effective for stimulating positive quality attitudes.

I should like to review the second step—organizing Quality Control so that modern results can be achieved at the same time that it can be fairly stated that the great bulk of plant the QC organization—both from the personnel is, in some sense, part of point of view of a general pattern of organization that is proving itself successful in industry, as well as from the point of view of why it has been difficult over the years in some companies to establish and maintain an effective QC organization according to this pattern.

Let us, therefore, turn to the general sequence for introducing a QC program.

INTRODUCING QUALITY CONTROL

The suggestion that a factory undertake a modern QC program may come from any of several quarters in the plant. It may be initiated by top management, which may have been impressed with the necessity for improved quality control activity in the plant or which may have seen the success of such a program in other plants. It may be proposed by functional heads, such as the chief inspector, the managing engineer, or the manufacturing superintendent. Quite frequently, it is suggested by relatively young members of the plant organization who are technical specialists.

The proposal to initiate modern quality control may be made as a sheer defense mechanism in the face of severe pressure on the plant—in the form of many field complaints, extremely high manufacturing losses, bitter internal feelings among plant personnel caused by unresolved quality problems. The initiatory proposal may be made as a suggestion to improve an already operating series of activities devoted toward the control of quality.

Wherever the modern quality control proposal is born and under whatever circumstances, the first major task for its proponents is a uniform one: A concrete, practical, salable plan must be developed for approaching the initiation and for outlining the ultimate objectives of a QC program for the plant.

It is very possible that the proponent of the QC program will not be a top-echelon member of the plant organization. He must then gear his plan for a review by top management such that management will be "sold" on deciding that modern quality control prospects are so attractive that the plant should "give it a try."

At least four general considerations must be taken into account during development of this plan:

1. *Individual Tailoring.*

An essential requirement is that the plant's quality needs must first be carefully analyzed. The QC plan being introduced should be one whose routines and terminology are tailored to the individual factory requirements as determined from this analysis. It should not be a "prepackaged" program lifted bodily from another plant or from the literature in the field.

2. *Economic Balance.*

The scope of the quality control activities recommended by the plan should be based upon sound economic analysis rather than be developed without reference to the economics of plant quality needs. This scope should be determined by striking a balance between the range of the quality problems in the factory and the cost of the minimum amount of control required to face and solve them.

3. *Participation.*

The QC plan will undoubtedly recommend action and cooperation from many functional groups and individuals in the plant. The support, involvement, and motivation of these individuals and groups are far more likely to be secured if they have participated in formulation of the plan and of the QC program it recommends.

4. *Emphasis upon Benefits.*

The plan should emphasize the tangible benefits that may be derived from quality control and should indicate the measuring sticks that will be regularly used in the program to evaluate the results produced. To the extent that actual applications can be cited of individual QC projects that have been successfully carried on in the plant, the salability of the entire plan will be much enhanced.

Acceptance of the forthcoming QC plan by top management, with whatever adaptations and improvements it wishes to make, is an essential without which no further genuinely effective selling can be done in the factory. Quality control proponents in many plants may properly be called upon to render considerable tangible evidence of the value of the activity before this approval is obtained for their plan. The approval may well be tentative, with complete acceptance contingent upon the results from initial QC applications.

When the plan has been accepted by management tentatively or otherwise, a sequence of several steps will be followed to bring its proposals into actual operating reality in the plant. This sequence will develop the plan through the stage where widespread tangible evidence will be available to all members of the plant organization on the actual value of QC activities. It will carry on the plan to the ultimate point where an over-all, factory-wide program of quality control is in operation involving the four basic jobs of a modern QC program, namely

1. *New-design control* involving the establishment and specification of the desirable cost-quality and performance - quality standards for the product, including the elimination or location of possible sources of manufacturing troubles before the start of formal production.
2. *Incoming-material control* involving the receiving and stocking, at the most economical levels of quality, of only those parts whose quality conforms to the specification requirements.
3. *Product control* involving the control of processed parts and assemblies at the source of production so that departures from the quality specification can be corrected before defective products are produced.
4. *Special process studies* involving the conducting of investigations and tests to locate the causes of defective products and to determine the possibility of improving product-quality characteristics.

The sales sequence for introducing these QC jobs includes four general steps which are quite fundamental in installing modern QC under a wide variety of industrial circumstances. These steps are:

1. Introduction by top management to concerned key personnel of the QC plan and the initial steps for placing it in operation.

2. A project-by-project quality control beginning in the plant, with full management support for these projects.
3. Regular appraisal of tangible results from the projects, as the number of projects grows and gradually evolves toward the planned factory-wide QC program.
4. Communication of quality objectives and of information on QC activities to all plant personnel, with encouragement of as wide a degree of participation as possible in the program.

Because of their importance to the development of quality-mindedness, it may be in order to review some of the highlights of the steps in this sequence of what has been termed the "responsible selling of quality control."

1. *Introduction of the Program by Top Management.*

Some degree of resistance among plant personnel to a program like modern quality control is inevitable. This resistance is generally caused by lack of information as to the procedures and objectives of the program.

Before any action is taken in the shop for establishing the activities proposed by the basic QC plan, therefore, it is highly desirable that top management should present the essentials of this plan to all key people. A presentation of this sort accomplishes several purposes: It provides a means for communicating to key personnel the basis for modern quality control; it tangibly demonstrates that the proposed program has genuine top-management support; it furnishes a channel wherein those individuals who have not yet had such an opportunity may participate in an over-all review of the proposed activities.

This introduction by management may be carried on quietly and informally if a private meeting is deemed best for plant conditions. Or management may wish to encourage widespread enthusiasm in the launching of modern quality control by holding a "full-dress" promotional meeting.

The promotional meeting may begin with formal presentation of the program by top management, possibly followed by some device such as a slide film with commentary to review the details of the QC activity.

This introductory meeting furnishes an excellent opportunity for announcing the selection of the individual who will be assigned the QC staff responsibility. The individual who will spark-plug the program may be immediately assigned on a full-time basis. He may, on the other hand, initially devote only part of his time to quality control with full time to be placed on the activity as it gradually develops. Wherever possible and practical, it may be most beneficial that the individual thus selected be a man who is already a member of the plant organization, familiar with its quality problems, and personally familiar with many of the individuals in the plant.

2. *A Project-by-Project Beginning.*

When the introductory meeting gives way to actual initiation of QC activity in the shop, only a few projects will be selected as the first steps. They may be carried on in the new-design-control field, in the incoming-material-control phase of quality control, or in either of the other two major jobs.

This project-by-project approach aids in the selling of the program to plant personnel through the medium of tangible quality control results. It also provides a practical means for tailoring the general quality control routines to the particular needs of the shop.

By selecting two or three of the most troublesome quality problems of the plant and obtaining success in attacking and solving them, then selecting more projects, the over-all program of the four QC jobs will gradually evolve in a form best adapted to the requirements of the plant.

3. *Tangible Results*

Since growth of the QC program will be directly dependent upon the results it produces, it is extremely important that adequate means for reporting these results be established. These reports are made by the quality control staff to top management and other key personnel on a periodic basis—perhaps daily, perhaps weekly, perhaps monthly. The initial reports are made on the first individual projects, and the coverage of the report is expanded as the QC activities expand. Great care is exercised in the reports to point out that the quality control results are due to the cooperative efforts of several functional groups and individuals rather than to the personal successes of the quality control staff.

The measuring sticks used may be drawn from a wide variety of elements, depending upon the plant situation. There may be reduction in complaint expenditures, reductions in manufacturing losses, improvements in design and in manufacturing processes, reduction in product costs, improvements in operator quality-mindedness, or reductions in machine overruns.

Many of the important results thus reported will be intangibles, but the most effective of all these results is that which can be measured against the very tangible measuring stick of dollars and cents savings. Quality control reports used during this phase of the selling process may tend, therefore, to give cost savings the most prominent place among all the measuring sticks used.

A similar analysis could be applied to Step 4—Communication and Participation—were space to permit.

Throughout all of this, QC education and quality training courses are employed as widely as possible. Success of this step in selling quality control is judged by the extent to which employees in the plant come to recognize the importance of their individual efforts to the design, manufacture, sale, and shipment of a product of acceptable quality.

But genuine sincerity and good will in carrying through the sound and responsible sequence of introducing quality control that we have been discussing will not guarantee full and complete positive quality-mindedness. Introductory techniques involve reviews of future promise; it is when these promises first begin to be seen as realities in the plant that quality-mindedness itself begins to be fundamentally affected. In effect, the plant QC program must be initially organized to produce a maximum of results with a minimum of friction; it must be initially organized so that its quality control staff—if the plant is large enough to support one—and all others closely connected with administration of the program can be the conscious, full-time stimulators of quality-mindedness rather than the subconscious foes of that spirit.

Let us, therefore, now turn our attention to the second of the major steps which must be taken to foster

positive quality attitudes during the early months of a modern QC program: namely, to organizing quality control so that quality becomes and genuinely remains the responsibility of every concerned individual in the plant.

ORGANIZING QUALITY CONTROL

The patterns emerging from industrial experience as most successful for effective organization may readily be summarized in their essentials.

In essence, basic quality responsibility rests in the hands of plant top management. Over the past several decades, top management, as part of the general industrial trend toward specialization, has delegated portions of its quality responsibility to such functional groups as engineering, planning, manufacturing, and inspection. In addition, the all-important responsibility of each workman for producing quality products has, if anything, increased over this period of years with the increasing complexity both of products and of production machinery.

In present-day industry, the four jobs of modern quality control cannot be effectively pursued with quality responsibilities for their various elements thus widely diffused and separated. There must be an associated mechanism for programming and controlling these responsibilities. In the larger plants where top management cannot of and by itself act as such a mechanism, present-day management establishes a small staff group as the pivotal point of its modern QC organization to provide the required coordination and control.

Creation of this quality control staff does not relieve other plant personnel of their delegated quality responsibilities for whose discharge they are best qualified. The staff group does, however, make the quality-control whole for the plant greater than the sum of its individual engineering, manufacturing, inspection, and marketing parts, through the functions of programming, coordination, and control.

Effective as this organizational pattern has proved itself to be, its establishment for a number of reasons has had a long and a hard road. For many factory QC organizations have never been squarely faced up to and reviewed. Instead, like Topsy, thy have 'just growed." They have become appendages to existing inspection departments, 'new" functional groups developed with little preliminary analysis of what their function should really be, additional assignments for strong personalities in the plants.

The QC organizations that are formally recognized on factory organization charts are often not adequate to administer a complete program of the four QC jobs. Some plants do not recognize that all four jobs are within the province of their QC organization. Others ally the "quality program" with what is essentially a traditional "sort the bad from the good" inspection department. Such a program concerns itself typically with incoming-material control, and with certain phases of product control but it is not organized to operate on an over-all, factory-wide basis.

Equally frequently encountered is the practice of creating a "modern" QC organization simply by adding such methods as statistical sampling to the activities of the plant's existing shop engineering department.

Again, there are often basic inadequacies in the program of those plants which concentrate upon the development of "new" functional QC organizations, entirely independent of inspection or engineering. Many of these groups have been built around a single quality control technique like the control chart, or a single quality control objective like the reduction of machine shop rejects. Some of these groups are statistical bureaus; others carry on specialized versions of sampling work or study only "manufacturing losses"; still others are responsible for troubleshooting field complaints or for writing factory inspection and testing instructions.

These groups are limited in scope to new-design control, to portions of product control, or to special process studies. Their members typically are extremely conscientious and often gain local successes in the individual projects they attack. In the final analysis, however, as is almost inevitable, the results of their work in relation to over-all plant quality objectives may be analogous to the results obtained in attempting to restrain a balloon by squeezing on one of its ends.

Knotty personality problems have sometimes arisen when top management has been led to expect from these forms of QC organizations the over-all improvements in quality and reductions in cost that have been reported in the literature. Frictions with other plant groups and employees, and high turnover of "quality control personnel" have characterized these programs. Employees throughout the factory are often not clear as to the scope of the QC organization and sometimes level "troublemaker" charges against its members.

On the one hand, management becomes dissatisfied with its QC program and suspicious of the national claims being made for the activity. On the other hand, members of the QC organization become frustrated and privately berate management for its lack of understanding and for its refusal to grant the group more power. The impact on plant quality-mindedness of such a QC organization may well be quite negative, on balance.

In the final analysis, many of these QC organizations have been so informal or so restricted in scope that they have not been QC organizations at all in the modern quality control sense of coordinated administration of a program of the four QC jobs. Individual elements of these jobs have been carried on, not as a part of the preconceived plant-wide modern QC program, but as uncoordinated portions of the regular responsibilities of several functional groups in the plant. New-design-control activities have usually been the exclusive province of design engineering and, possibly, planning and methods, and other plant groups have been forbidden to participate. Incoming-material control has generally been supervised by inspection and laboratory engineering.

Product control has usually been the exclusive preserve of manufacturing supervision. Specific process studies have frequently resolved into free-for-alls in which all groups would participate at one time or another.

To be sure, these individual quality responsibilities are and must be integral parts of the day-to-day work of the line, staff, and functional groups which hold them. They cannot be effectively wholly separated out from the other activities of these groups. The few efforts to organize quality control in this direction have proved highly unsuccessful, as when

Quality Managers have been appointed for brief periods with the vague and unsatisfactory charge of being "responsible for everything affecting quality." How then, can quality control be organized so that the badly needed programming, coordination and control are provided without relieving the rest of plant personnel of its basic responsibility for quality?

This problem of diffused responsibility is not so knotty as it may seem at first glance. It has been faced and solved by management on several previous issues.

It was faced in the development of organization for personnel administration. It was inconceivable that all personnel activities be stripped from the line organization and be placed in the hands of a personnel group.

It was faced in the development of production control organization. It was clearly seen at the outset of this program that responsibility for many phases of production must remain where it was—in the hands of the factory foreman, the engineer, and other parties to the production process.

The organizational technique developed by management to meet these conditions can be simply described. It consists initially of leaving untouched responsibilities and authority in the hands of the groups to which they have been delegated. This procedure is followed whether this delegation had previously been formally made by management or whether the responsibilities had informally gravitated to the groups in question over a period of years.

A means is then created for assuring management that the results of these groups are satisfactory in relation to present management standards. In the process of this results check, it may become necessary to coordinate the activities of the several delegants and to redistribute some of their responsibilities.

Management often has not the time to carry on the work that is required. It may therefore "extend its personality" by creating a staff man or a small staff group to do this work for it.

This process is, as is well known, called one of "control." The term control is usually applied to the organization that is correspondingly created as in budget "control," production "control," and, of course, quality "control."

Analyzed from this organizational point of view, quality control becomes merely what the phrase implies—management's over-all control on product quality. It is a device whereby management delegates authority and responsibility for product quality, thus relieving itself of unnecessary detail and permitting the benefits of specialization, yet retaining for itself the means for assuring that quality results will be satisfactory, in terms of top management's standards and policies.

In small plants the control called for can be personally exercised by the chief executive along with his other duties. In the larger factories, the size or complexity of the enterprise may make it impossible for the chief executive personally to discharge this responsibility. He is required to employ a staff "QC engineer" with assistants as needed. But the QC engineer, while a key man, is merely one member of the plant QC organization; he is joined in his membership by the many specialized groups and individuals in the factory who have specific quality responsibilities and authorities—factory foreman, design engineers, planning and methods men. Quality control organization in this sense, as it has been experienced in an increasing number of industrial plants, does indeed make the quality control whole greater than the sum of its individual parts.

It in no sense diminishes the foreman's quality responsibilities and authorities; yet by making him a full-fledged member of the QC team, it broadens his ability and information for discharging his quality responsibilities. It in no sense diminishes the design engineer's responsibilities and in fact helps buttress them. If anything, by bringing him into design control meetings—by making it possible for him to plan inspection—it expands the inspector's quality responsibilities.

Good QC organization has, therefore, a very strong and influential result in encouraging quality-mindedness, in fostering positive attitudes toward quality and the modern means for its control. The acid test of the adequacy of QC organization, in fact, is and must be just how well it cements into a unified whole for the plant the quality-minded attitudes whose forming was begun during the activities involved in the initial introduction of the QC program. The test is, in effect, just how effectively the QC organizational structure contributes toward the development of a plant attitude which is based upon living, talking and acting quality.

SUMMARY AND CONCLUSION

In summary, the greatest single quality resource of a plant is the conscientious workmanship of its people. Successful management of modern quality control is not, therefore, at its base chiefly a matter of utilizing the best technical quality methods, nor chiefly a matter of employing the best measuring equipments, nor even chiefly a matter of procuring and operating the best production and research facilities.

Successful QC management depends principally upon fostering, throughout the length and breadth of a plant, positive attitudes toward quality. First impressions are as important in quality control as they are elsewhere. Crucial to the development of quality-mindedness in the plant is the impact upon plant personnel of the effects of the first few months of the operation of a new QC program.

This impact can be planned to react positively in fostering quality-mindedness, if at least two steps are emphasized while the new program is being installed:

First: Introduce quality control to the plant in a manner designed to create an environment where quality-mindedness is encouraged, and

Second: Organize quality control in a fashion whereby the most up-to-date techniques may be employed at the same time that there is full participation in the program by the plant personnel who are concerned.

Through these steps, it becomes genuinely possible to make a QC program truly effective and harmonious as a plant-wide effort for improving product quality and design and for reducing costs and losses. It becomes possible to allow the QC program over the weeks and months to grow into industrial management's strongest ally in achieving a key management objective: to manufacture products into which quality is built and maintained at the most economical costs which yield full customer satisfaction—an objective whose achievement is in turn the key target for successfully managing modern quality control so as to encourage quality-mindedness.

Installing a Quality Control System

J. M. JURAN

Consulting Management Engineer

BECAUSE the words Quality Control mean many things to many people, it is useful at the outset to define terms. Most managers of my acquaintance would agree with me if I defined Quality Control as the means for achieving defect prevention. Such is the meaning I will give to the term in this article.

My first point is: *The tools for defect prevention are numerous and varied.*

Because the causes of defects are widely varied, the means for prevention must be correspondingly varied. Let me list a few of these causes and the corresponding cures so that we may see in perspective this collection of preventive means.

Within the orbit of the machine operator we recognize that four requirements must be met simultaneously. We can tabulate these requirements and the means for meeting them:

Requirement	*Means*
The operator must know what he is supposed to be doing; i.e., he must know the specification for the product or process	Disclosure of this information to the operator, through publication, training, etc.
The operator must know what he *is* doing; i.e., he must have means for knowing whether or not he is meeting specifications	Provision of adequate standards, gages and instruments, plus training in their use
The operator must have means for regulating the process in the event of failure to meet specification	Provision of adequate adjustments in the machine or process; training in use of these
The operator must have the determination to use all these means to produce conforming product	Provision of adequate incentives; launching a campaign to increase quality-mindedness

So far, in talking only about the problems of the production operator, we have already listed, as tools for defect prevention, good employee communication, good training, development of quality standards, improved instrumentation, improved machine design and process engineering, improved incentives, and a campaign for improving quality-mindedness. (This last is itself a whole collection of tools).

The foregoing list requires contributions from the personnel specialist, the inspection supervisor, the instrument designer, the machine designer, the process engineer, the industrial engineer and still others. Several branches of engineering, and several branches of the social sciences are already involved.

A great many causes for defects are simply unknown. A usual symptom here is that each man points to someone else as being responsible for the defects. The cure for such cases is to collect new and essential data, to analyze them and to present the findings in a way which stimulates action. We may here add to our tabulation:

Requirement	*Means*
To collect the new essential data	Standards and instruments; design of experiments; organization (to provide a trained fact finder)
To analyze the data	Statistical know-how
To secure action on the facts	Statistical summary and graphic presentation; salesmanship to sell the conclusions

We can now add, to the preceding list of means, the tools of statistics, organization and salesmanship.

Nor is this all. Before much concerted effort can be brought to bear on the problem of defects, there must be a selling job to top management on the merits of such a concerted effort. This increases our tabulation as follows:

Requirement	*Means*
Determination of the total cost of avoidable defects	Analysis of accounting reports; analysis of inspection reports
Preparation of a budget for a defect prevention program	Accounting and engineering analysis
Development of an organization plan to launch and sustain a program	Organization planning
Development of targets for defect reduction for various departments	Accounting, inspection and engineering analysis
Development of executive reports for executive control	The "executive instrument panel"

To our list of means we have added accounting, budgeting, organization planning, executive reporting, and some additional specialties of engineering.

And this isn't all either. We have made no mention of market analysis to see what are competitors doing; of consumer research to study consumer preferences and consumer ability to discriminate. We have made no mention of complaint analysis, or of relating field service data to design and manufacturing data.

The foregoing should make clear that defect prevention requres a wide variety of tools because defects have a wide variety of causes.

I now return to the subject of this article, "Installing a Quality Control System" which, under my definition, becomes "Installing a Defect Prevention System." It is clear that there is a wide assortment of tools necessary to constitute a "system" for defect prevention. It should

be equally clear that emphasis on but one set of tools such as the tools of machine design, or instrument design, or statistical methods, or accounting analysis, runs a serious risk of failure because the causes of defects are too numerous and complex to be solved by any one set of tools.

My second point is: *Such a wide variety of tools requires the participation of numerous departments in the company.*

The accounting department determines the cost of defects, prepares a budget for a defect prevention program, and keeps the score on how the program progresses. The sales department is involved in analysis of customer complaints, in market research and in consumer research. The product designers are involved in establishment of engineering tolerances and standards. The personnel department is involved in training, in communications and in any program for quality-mindedness. The process engineers are involved in machine design, process development, and instrument design. The inspection department is involved in the setting of standards and in collection of data. The production supervisors are involved in training, in stimulating operators, and in detailed corrective action. The industrial engineers are involved in organization planning and in wage incentives. The quality control engineers are involved in engineering and statistical analysis. Top management is involved in coordination and in executive controls.

This is a formidable list of organizations. Yet they are all there. Any omission not only deprives the program of the potential aid of departments who have a contribution to make; it engenders the opposition of such omitted departments.

My third point is: *Collaboration among numerous departments requires a plan.*

It hardly requires elaboration to point out that so broad a list of departments can best work together only if there exists a well thought out plan on how they can and should work together.

In a recent paper* I reported on the results of quality control programs started since World War II by 39 companies. That study disclosed a shocking mortality rate for these programs. The failures were largely due to failure to utilize the managerial tools for defect prevention while at the same time over-emphasizing the statistical tools. It is primarily for the heads of quality control departments to avoid such failures by expanding their own horizon to include *all* tools for defect prevention, not just the statistical tools.†

The more nearly the actual program includes the following list of steps, the greater is the probability of success.

1. Compute the "gold in the mine"—how much less it would cost to operate if there were no defects, no failures to meet specification.

2. Estimate how much of this is avoidable. If the company has never gone into a modern quality control program, you are pretty safe in assuming that half the "gold in the mine" can economically be saved. *This estimate of avoidable loss is a cardinal figure.* The extent of avoidable loss automatically decides whether a program is needed at all, how big the program should be, and what should be the time table.

3. Determine how the avoidable loss is distributed among departments, products, processes, etc. This distribution is necessary to establish the order of priority for study and to establish the improvement quotas.

4. Determine how the avoidable loss is divided as to responsibility, whether operator responsibility, non-operator responsibility, or unknown responsibility. This division indicates the proper emphasis of the program as between a campaign for quality-mindedness vs. a campaign for fact finding.

5. Establish a steering committee or other organizational device for securing participation of all interested departments in putting the program into effect. Give this committee responsibility for:

   (a) Identifying what are the major quality problems of the company
   (b) Considering possible improvements in handling these major problems
   (c) Recommending solutions
   (d) Observing and following progress made in solution

6. Estimate the budget needed for fact finding (quality control engineers), for putting on a campaign for quality-mindedness, for score-keeping and for other necessary activities as developed by the steering group.

7. Set up a plan of action for all departments, including a set of quotas for improvement, and a time table for securing the improvements.

8. Organize or expand a quality control department to a size appropriate for the extent of avoidable loss. During 1951 a common ratio was one quality control engineer for each 500 production operators.

9. Set up a system of score-keeping on avoidable loss to enable non-supervisors, supervisors and executives to follow the progress of the program.

10. Set up appropriate training programs for supervisors and other key personnel. Here again do not make the mistake of restricting the training to use of only a few specialized tools.

11. If there is need for a campaign for better quality-mindedness, a special series of steps is involved. The purpose of these steps is:

   (a) To demonstrate to each operator how the company's quality is important to him, personally
   (b) To show him how he can personally make a contribution to better quality at lower cost
   (c) To stimulate him to make that contribution

To achieve all this requires special means including:

   (a) Contests for slogans, for quality improvements, and for suggestions
   (b) Posters, articles in the house organs, displays of good and bad work, and other means for communication to employees
   (c) Special training material to stimulate operator interest, to show how to tell good work

*Juran, J. M., "Insure Success for Your Quality Control Program," *Factory Management and Maintenance*, October, 1950.

†I might note, in passing, that recognition of this very point is going to be decisive on the success or failure of the American Society for Quality Control as well. The Society must debate this issue to determine whether it will become a forum for development of all tools for quality control or whether it will confine itself only to the statistical tools for quality control.

from bad, and how to prevent defects from happening

(d) Measure of operator quality to discover and reward the successful operators, and to discover and train the unsuccessful operators

My final point is: *The Quality Control Department must concern itself primarily with the overall plan,* and only secondarily with the special tools in which it is skilled.

The prime job of the quality control department is to develop an overall program for defect prevention, to define the role of each department in that program, to coordinate these various efforts, and to measure and report the results.

A secondary job of the quality control department is to contribute to this overall effort those special tools in which it has special skills, the tools of engineering and statistical analysis.

At the risk of over-simplification, may I assert that to date, the quality control departments have largely devoted themselves to their secondary job while neglecting their primary job. Thereby many programs have failed or stalled.

In making this assertion I am not attempting to lay blame—I am attempting merely to be realistic. There is no "blame." It takes good industrial experience and particularly a breadth of managerial experience to see the broad perspective of industrial operation. Most of the men selected so far to head quality control programs have had prior technical and statistical experience rather than managerial experience. Under the circumstances, those who rose to the occasion have shown remarkable adaptability, since they had to be virtually self-teaching in perspective, and that in a short time.

Conclusion

The prime (though not the sole) purpose of quality control, as interpreted by industrial executives, is to prevent defects from happening.

Defect prevention requires use of numerous tools in the natural and social sciences. Skill in the use of these numerous tools is scattered among various departments of the industrial company. Maximum effectiveness of the defect prevention program is achieved only when there is a definition and a coordination of the roles of all these various departments.

In many companies there have been established QC departments for the prime purpose of defect prevention. In the view of the executives, it is the prime mission of these QC departments to marshall all of the companies' various skills for defect prevention into one unified program.

Many QC departments have missed the point here. The reason lies in the fact that these departments are themselves skilled in use of the special tools of engineering and statistical analysis. Possessing these special tools and skills, they have concentrated on promotion of those tools and skills. But they have done this to the neglect of the broader and more important problem of generating an overall program in which all departments can participate.

The record in companies which have emphasized the broad program is one of comparative successes. In sharp contrast is the record of comparative failures in companies which have emphasized use of a few limited tools.

The contrast in performance suggests also the need for a re-appraisal of the job of the QC department. QC engineers and particularly the heads of QC departments must widen their perspective drastically. They must regard their prime job as the harnessing of all skills which can aid in defect prevention, wherever those skills may be found in the various departments of the company. They must resist any temptation to consider their personal skills as the hub of the program. The available records indicate that the more this temptation is resisted, the greater is the probability that the program will succeed.

The Technique of Preventing Defects*

LEONARD A. SEDER

Gillette Safety Razor Company

LET us start with the flat statement that "Quality Control is the science of preventing the manufacture of defective product." There are many who might quarrel with that definition of quality control as being too limited in scope. In the sense of a definition, they are probably right. On the other hand, as a capsule statement of the importance with which the preventive point of view must be reflected in any serious attempt at modern quality control, it would find many adherents.

The most noted exponent of this idea has been Dr. J. M. Juran, who has made a careful analysis of the reasons why some quality control programs succeed and others fail. He says: "There must be a recognition of the fact that the basic objective is prevention of defects and that all else is secondary."[1] Whether we wish to define quality control as defect prevention or not, it is true that, aside from the employment of statistical methods, the preventive philosophy is the one, single, new and significant concept that distinguishes modern quality control from its predecessors in the field of industrial cost control.

Juran has woven the theme of defect prevention into much of his writing and no discussion of the techniques for preventing defects can start without a brief review of some of his brilliant analyses and arguments along these lines. Juran[2] sees the quality function in industry as comprising three main elements:

1. Acceptance
2. Prevention
3. Assurance

Acceptance is the daily inspection job of accepting and rejecting specific items of product. It embraces both 100 percent inspection and sampling inspection, whether performed on incoming raw materials, parts in process, sub-assemblies or on finished articles ready for shipment. It includes keeping records and charts and doing day-to-day trouble shooting.

*Paper presented on the program of the Sixth Annual Convention of ASQC in Syracuse, New York, May 1952.

Prevention is the "quality control engineering" job, utilizing all of the modern statistical and managerial techniques, aimed at solving quality problems and devising means to prevent their future recurrence. Among the techniques used are: process capability analysis, control chart analysis, design of experiments, design of sampling plans, and others.

Assurance is the job of determining the existing quality of product and policing the system for maintaining quality. It involves the techniques of check inspection, quality audit, analysis of consumer complaints, determination of market quality, and others.

This breakdown by Juran is primarily designed to show the separate nature of the three quality control jobs and to suggest a form of organization through which the complete quality function may be fully covered. It does not infer that the prevention concept is limited to one specialized regiment of the quality control "brigade"; skill in applying prevention *techniques* may be concentrated in a small part of the organization, but the *philosophy* of prevention must pervade the entire quality control activity.

Reflect, for example, on the singular ineffectiveness of a sampling inspection acceptance plan in which no provision is included for notifying the producing operator of the rejection of a lot. Or consider the spinelessness and futility of a quality assurance plan which management refuses to take seriously enough to spur an investigation of the reasons for extraordinary deviations. Neither of these acceptance or assurance jobs has a "built-in" prevention device. As every quality control neophyte has been told and every practitioner knows, no technique can succeed or survive unless it is linked securely to the preventive idea. The statistical techniques are no exceptions. They contribute to all three elements of the quality function, but they can do little if managment is unwilling to accept the preventive philosophy.*

*It is seldom, of course, that management is actually hostile to the preventive philosophy, but the author knows of at least one instance where efforts to apply quality control techniques were unavailing because of such hostility. It occurred in a paper manufacturing company subsidiary of a large publisher. Because of this consanguineous relationship, top quality paper was sold to the parent company at cost price, whereas "seconds"—sold on the open market—actually commanded a higher price. Clearly, management of the subsidiary company had little incentive for adopting a preventive attitude toward defects.

The idea of prevention is obviously not a new one. Indeed, there is scarcely a field of human endeavor where it has not taken hold, once the knowledge and tools for prevention become available. Fire prevention, crime prevention, preventive medicine, preventive maintenance and accident prevention are a few of the fields in which the idea has successfully germinated. Each of these is actually the outgrowth of an activity originally established—and still existent—to cope with the immediate effects of the "disease, death or disaster", i.e. fighting fires, detecting crime, healing the sick, repairing the wreck, etc. But the human mind is not content with putting out fires; from the accumulated experience of fire-fighting, it seeks out the most frequent causes of fires and, once these are known, it devises techniques and programs to battle these causes.

The defect-prevention idea was born of the same circumstances. It came from the observation of repeating patterns in the causes for defectives and powerful desire to battle these causes. It is simply the concept that it is far better and cheaper to prevent defects from happening than to suffer the toll they take in dollars and morale.

Ten years ago, this was still largely an idea. Today, however, there is little doubt that this idea, together with the techniques for achieving it, is one of the most powerful means for reducing scrap, rework, complaint and inspection bills in industry. Many have pointed to the lush savings they have been able to secure. Juran's widespread experience in a number of companies leads him to the statement that a good quality control program can usually succeed in reducing the "cost of defects"—which includes those items listed above—by 50 percent.[6]

TECHNIQUES FOR DEFECT PREVENTION

What, then, are the means for achieving this desirable situation? Te begin with, we must divide them into two broad classes:

(a) Those which are employed when the know-how for prevention is available, but is not being used.

(b) Those which are employed when the know-how for prevention is not available and so must first be obtained.

When a machine or process is producing parts that normally meet the specification requirements and when the operators of these machines or processes fully understand the operation and adjustment of the process, then the know-how is available and there is no reason why defectives should be made. But often they are made, because the operator is careless, or is working on a poorly-conceived incentive system, or because the foreman insists on running the machine too fast, or because the material specification is changed without adequate investigation, or because . . .

When this situation is rampant throughout the plant, then it is obvious that use is not being made of existing know-how. Prevention of defects is then a human relations problem and it must be attained through the careful use of the many ways of influencing human behavior. Some of these are: development of better working conditions, better supervision, better disciplinary methods, better incentives for quality, educational campaigns based on posters, slogans, contests, etc. All of these seek, through indoctrination with "quality-mindedness", to achieve that kind of working environment in which the preventive philosophy can be successfully nurtured.

However, when the know-how for preventing defectives is simply not available, then no amount of exhortation of incentive—however cleverly contrived—can bring about the desired quality improvement. In the complex fabric of modern mass production—with the quality responsibility divided among many hands and minds—it is fairly common to find that the know-how does not exist. Ultimate failure of the product to meet specifications may arise from many sources and, until new facts are collected and analyzed, it is impossible to determine how to prevent defectives. Such situations vary in complexity all the way from simple machine operations, where a few hours of fact-finding will suffice, to the more complicated processes involving several operations that may require several months of experimenting and fact-gathering before a control system can be achieved.

The development of this necessary know-how involves a three-fold mode of attack.[6]

1. Reliance on the scientific method of collecting facts instead of on opinions.

2. Analysis of these facts by specialists trained and qualified in the new techniques.
3. Coordination of results to provide the necessary action or modification of existing practices.

If such a program of defect prevention is carried through, it will ultimately affect every function in the enterprise. For it becomes crystal clear that the defect-prevention attitude must start with the design of the product, carry through the planning, manufacturing, inspection and testing stages and not end until the product is in the hands of a satisfied customer.

Let us examine in more detail how the prevention function operates in developing and analyzing new facts to improve existing know-how.

ROOTS OF DEFECT-PREVENTION PROBLEMS

The basic tenet of the defect-prevention "faith" is the belief that defects have causes, they do not "just happen." It then follows axiomatically that the cause of a particular defect can be discovered. Once discovered, it is held that human ingenuity will usually be able to devise a method of eradicating or minimizing the cause. In brief, these causes or "roots" may be multitudinous, but they are not mysterious.

A convenient and alliterate classification of the roots of defect-prevention problems is given by Feigenbaum,[6] who uses the headings: Men, Materials, Methods, Machines, Management. Utilizing this classification, let us list some of the typical situations in the industrial environment that lead to the manufacture of defects.

Men

1. The engineers who create an impossible design or impossible tolerances.
2. The planning men who provide inadequate equipment
3. The purchasing agent who selects an unqualified vendor or who fails to acquaint him with the quality requirements that do not appear on the blueprint
4. The time-study man who sets the price too tight, or who fails to allow for operator-inspection when it is feasible
5. The operator and/or inspector who does not have the necessary skill or is not conscientious, or is not properly trained.

Materials

1. The purchased material that is never inspected until it arrives at the assembly department and will not fit
2. The purchased material that is out of specification, but has to be accepted anyway because "we can't afford the delay of rejecting it"
3. The purchased material that is made wrong, but could just as well have been made right if only the vendor had known what was really wanted

Methods

1. The measuring or testing instrument that is not sensitive enough to reveal the location of the process *within the tolerances*
2. The inspection procedure that waits until all the parts are made before deciding whether they are good or bad
3. The gaging system that measures two unimportant dimensions to control a functionally important dimension instead of measuring that dimension itself
4. The method of specification that establishes tight tolerances to compensate for shop laxity; they are not really expected to be met and so nobody pays any attention to them
5. The worn jigs and fixtures, the inaccurate tools, the obsolete gages that continue to be used because "that's all there is; there ain't no more"
6. The heat-treating cycle that was specified in a hurry one day five years ago and never has succeeded in producing the right hardness

Machines

1. The machine that does not have the capability to meet the tolerances
2. The makeshift machine that was designed for another use, but was adopted temporarily—two years ago
3. The machine with the worn ways or the wobbly spindle or the egg-shaped shift that should have been fixed, but the accounting department said it wouldn't increase production enough to pay for itself in six months

Management

1. The management policy that pays piece work rates for total production instead of good work only
2. The superintendent who berates his foremen soundly for failing to meet the production quota but never even glances at their quality record
3. The foreman who mouths pretty phrases about getting the right quality, but howls like a stuck pig when some inspector takes him seriously and shuts down a machine to help him get it
4. The boss who spends all his energies fighting inspection instead of fighting the defects and eliminating the need for inspection
5. The executive who bemoans the passing of "pride of workmanship" as a lost art instead of searching out means for restoring it

The list could be extended for many more pages, but the idea is clear—this sort of thing is the "stuff" defectives are made of. It should also be evident that the specific cause of a particular defect will never be obvious until the fact-finding and analysis has been carried out.

FINDING THE RIGHT PREVENTIVE DEVICE

After the roots of the problem have been located, much consideration must be given to the question of finding the right type of preventative device. Excluding the situations having purely mechanical solutions, it can be said that there is a right preventive technique for the particular time and place, but that the same technique may not be right for the same problem at a different time or in a different plant. There is, in other words, a kind of fourth dimension about the selection of the preventive technique to be used. Not only must it solve the particular defect problem to which it is applied, but it must be physiologically adaptable to the environment and the personnel who must use it at that particular time.

A good example of the temporal propriety of the preventive technique is afforded by the following review of the history of one particular problem through four separate phases over a space of four years.

First Phase

In the assembly department of a certain high-volume operation, a study was made of the frequency of occurence of certain types of defects. It was discovered that the major cause of assembly rejects came from defective soldering in one of the subassemblies. So costly was the process of tearing down the assembly, stripping the defective parts, resoldering and replating them that it was decided to institute a 100 percent inspection of soldered parts prior to plating and asembly. For this time and place, this was an appropriate preventive technique. It took the problem out of the assembly department—where little could be learned of cause and effect—and put

LAUNDERING OF SHIRTS — Lot Size - 1,000 — Sample Size - 100

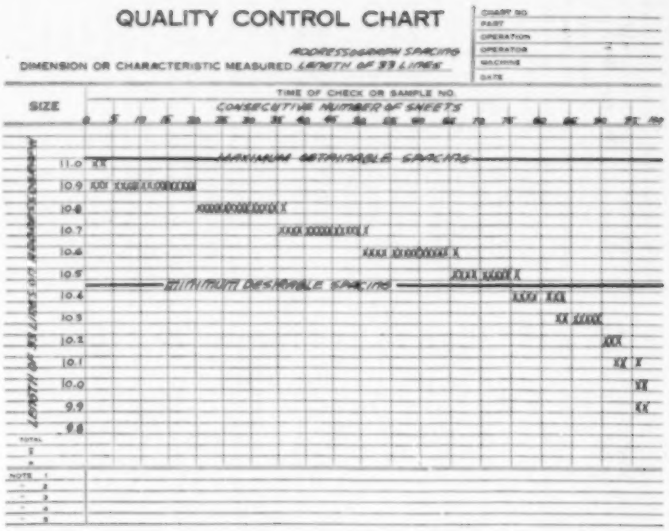
Day	Time	CAUSE FOR REJECTION: Wash	Starch	Iron	Pack	Misc.	TOTAL REJECTS
1	1:00 P.M.		/	𝍸		/	7
2	2:30 P.M.	〃	/	〃	/		6
3	11:45 A.M.	𝍸	〃	𝍸			12
4	11:45 A.M.		/	〃		/	4
5	3:00 P.M.						0
6	1:05 P.M.			/			/
7	10:00 A.M.	/		〃		𝍸	8
8	1:00 P.M.	〃	/		///		6
9	4:00 P.M.	〃		𝍸			8
10	2:00 P.M.		/	〃			3
11	1:00 P.M.						0
12	11:00 A.M.	/	/	/	/	/	5
13	11:45 A.M.			////			4
14	11:20 A.M.	/	/	𝍸		/	8
15	3:35 P.M.					𝍸	5
16	3:00 P.M.			////	/	〃	7
17	10:00 A.M.	/	〃	〃		/	6
18	2:00 P.M.	〃	/	///		/	7
19	1:30 P.M.		〃	////			6
20	2:00 P.M.			/			/
	TOTALS	18	14	48	6	18	104

$\bar{p} = \frac{104}{20 \times 100} = .52\%$

PREVENT DEFECTS IN A LAUNDRY?

Fastidious male customers were complaining about stains, starch streaks and crumpled fronts in the shirts they received from the Home Laundry Co. The sales department investigated with a simple fact-finding device: every day for 20 days, a salesman made an unannounced visit to the "accumulation bins," last stop before boxing and delivery, scooped up 100 shirts and submitted them to a jury of salesmen for inspection. Shown above is the tally sheet with defects sorted by descriptions. "Ironing" stood out like a sore thumb. A campaign of operator-education among the ironers, coupled with clarification of quality standards and introduction of inspection *by the ironer* quickly brought the five-percent level shown above to one percent within two weeks. Home Laundry Co. learned how to cut its complaint bill.

(Thanks to C. T. Capasso)



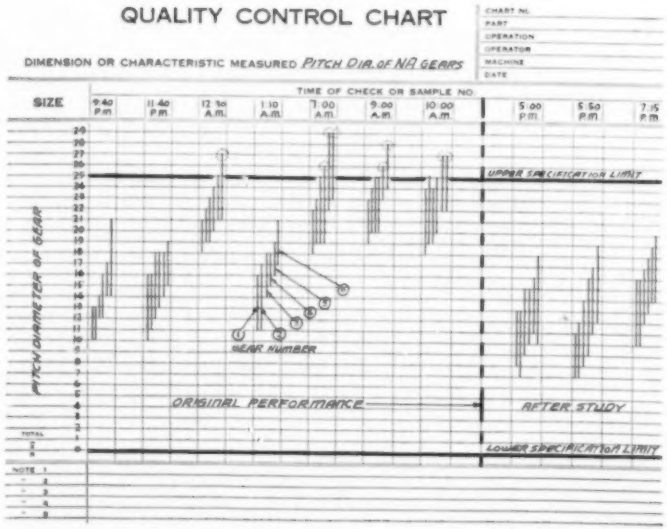
PREVENTION PAYS OFF AT PAYROLL

The unfailing ability of most payroll departments to come up with the right amount in your weekly pay envelope is not often open to question. But in one payroll department of a government agency, this long-held prestige was shaken by a series of inexplicable errors. Inexplicable, that is, until traced to errors of "registration" in the weekly "money list" used to make up the pay envelopes. In preparing this list, names of employees were stencilled on with an addressograph machine while the amounts due were typed on. Frequently, the line-spacing of the two machines did not jibe and, as the error accumulated, a man's name and his stipend could be separated by several lines. All this in spite of the protests of the addressograph operator who steadfastly maintained that she always set the spacing adjustment screw right when she started the weekly job.

The "right" spacing would give just about $10\frac{3}{4}$ in. for the 33 names stencilled on a page, since 33 lines of typing run that long. When a QC-minded investigator examined the actual spacing of the first 100 payroll sheets off the machine, he obtained the graph above. It was a dead giveaway for the slipping adjustment screw, like deertracks in freshly-fallen snow.

The new adjustment screw restored the payroll department's sagging prestige. To preserve that prestige in the future, the addressograph operator now makes a periodic check of the money sheets as she prints them.

(Thanks to John C. Arnold)

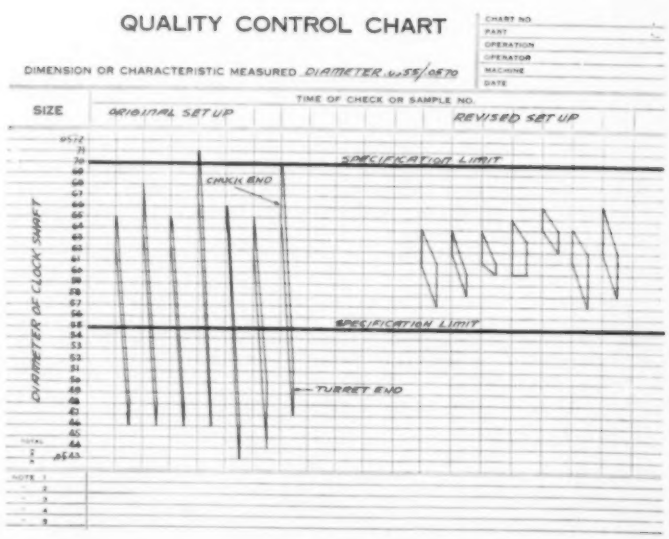


GETTING AT THE GUTS OF GANG GEAR CUTTING

Holding pitch diameter tolerances of 2.5 thousandths on gang-cut gears is no picnic even with a precision Pratt & Whitney profile gear grinder. For one thing, the gears are never quite round, so where do you take the measurement? The inspectors at the Prime Pump Co. seemed to know the answer; they rejected plenty of them for over- and under-size pitches. These losses were a chronic disease until the QC boys came up with a multi-vari chart study, partially reproduced above.

Each of those lines shows the minimum and maximum of seven diameter readings on a gear. The length, then, is the out-of-roundness and it isn't nearly as bad as everyone had thought. But look at the "trend" effect from the first to the sixth gear on the gang arbor. No one realized that. And look where the operator has his process set—right out to the edge of the cliff. No wonder he falls off every now and then. Pictures like this are powerful; it convinced the operator to pull down his process setting and told him how much to allow for the "trend." The inspectors are having a hard time finding defectives now.

(Thanks to Maurice B. Ahern)

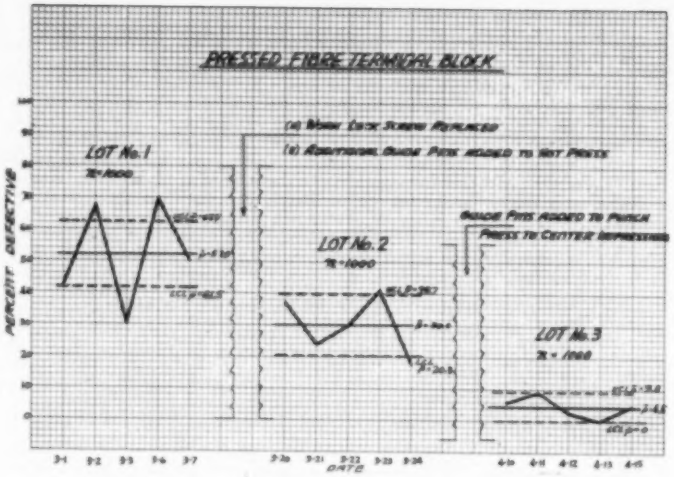


IMAGINATION WITH CLOCKWORK

The hands of a clock are pressed on to the nose of the clock shaft and are meant to stay there, not fall off. But they were falling off at the Caldwell Clock Co. and it made everybody mad,—the assemblers, the foremen, and especially the inspector who checked the spindle pieceparts at the automatic screw machine. He insisted he always carefully checked the end section of the spindles and that they were within the 0.0015-in. tolerance.

But an imaginative QC engineer proved him wrong with the multi-vari chart pictured above (on the left). Although the end section was only 0.033 in. long the QC man visualized the possibility of taper and checked each end of the section; the inspector had simply applied his micrometers to the whole section. Examination of the tool holder mounting hole in the turret head of the screw machine proved that it had worn egg-shaped and was causing the taper. An imaginative set-up man came to the rescue this time; by matching the out-of-roundness of a discarded tool holder to the out-of-roundess of the mounting hole, he was able to produce the multi-vari chart on the right. Until there was time to shut down the machine and re-bush the hole, this ingenious stunt stopped the flow of tapered spindles. Needless to say, the clock hands have stopped falling off and time has been saved.

(Thanks to George F. Mason)



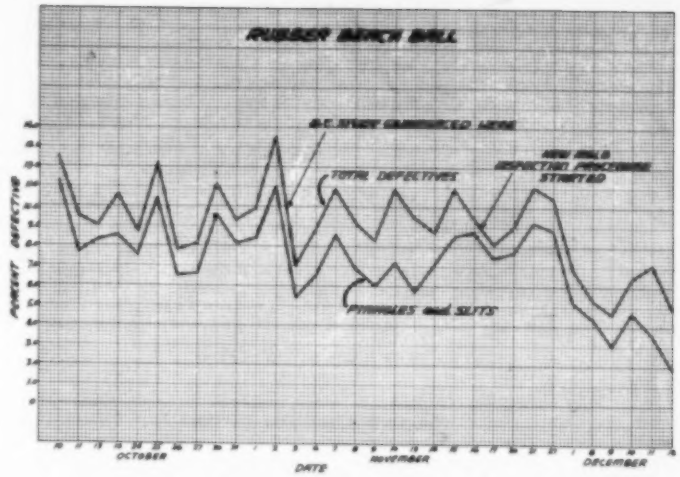
BUT WE'RE A JOB SHOP; OUR PROBLEM IS DIFFERENT!

That's what the Penult Pressed Fibre Co. thought until they really studied the terminal block job. It was ridiculous to have so much trouble with such a simple part—that rectangular fibre strip with the square hot-pressed impression and the three punched holes. And yet, every time the order came through, it was a sure signal of trouble and Penult's customer got madder and madder every time he shipped the whole lot back to do over.

This time, they didn't run the whole lot of 3,000 through; instead, they took 1,000 and watched them carefully from the cutting press to the hot press to the punch press, inspecting the whole lot and making notes at each step. Armed with these facts, it was easy to prove that the 52 percent defective happened right at the cutting operation because a lockscrew kept slipping. They fixed the screw, and added a "built-in" defect preventer—extra guide pins at the second operation which would refuse to accept oversize pieces.

The second lot fared better; it was only 30 percent defective. Luckily, they had kept watch and again were able to point to the culprit—a missing guide pin in the punch press operation. The third lot hit the jackpot—only 4.5 percent defective—and it really looks like Penult can stop worrying about the terminal block job.

(Thanks to E. J. O'Brien)



WHEN BEACH BALLS DON'T BOUNCE—POUNCE!

If you were making rubber beach balls and had ten percent of them ending up in the scrap pile, you wouldn't be any happier than was the management of the Bounce Ball Co. But when you learned that 8.5 percent were "pinholes and slits," you would make up your mind to apply the preventive philosophy, especially if you knew that cracked or dirty molds were the prime cause of these tiny defects. You probably would, as they did:

1. Identify each production mold, inspect it weekly, yank it for cleaning when it needs it.
2. Develop a new film coating material to apply after cleaning.
3. Use X-Ray inspection of all new molds to look for cracks.
4. Develop a fixture to let you inspect the balls before vulcanizing the stem so you could ove your inspection that much closer to the source of defectives.

You would have been mighty pleased, too, to see the pinholes begin to wane in December, as the graph shows. Your next step is to move the inspection right back to the molding operation to catch the defects even sooner.

(Thanks to J. P. Cahalane)

the burden of the defectives back into the department responsible; it could not help but stimulate interest in the problem if the defectives were sorted out "on the spot" and and exhibited to all those directly concerned with the soldering.

Second Phase

As expected, this scheme successfully prevented assembly rejects, and the defect prevention problem was moved back to the soldering department. When the results of the 100 percent inspection were accumulated, it became evident that 15-20 percent of the sub-assemblies did not meet the soldering standards. To study this situation, arrangements were made to identify the work of each of the 12 soldering machine operators through the 100 percent inspection. Analysis of the data revealed the interesting fact that not all of the operators were equally responsible for the defectiveness. The work of some operators was distinctly superior to that of others. This led to the substitution of sampling inspection at the machine in place of 100 percent inspection. The trick was to move the defect detection device one step nearer to the scource of the defects and provide much stronger pressure on each operator to "make 'em right in the first place."

Third Phase

The result of this change was startingly dramatic. Within a few weeks, the defectiveness dropped to about two percent. Each operator could now see the disposition of her own work and knew that a record was kept of her individual performance. She began to inspect her own work and make the necessary time and voltage adjustments to the soldering machine (actually an adapted welding transformer) whenever she was not satisfied with the quality. This preventive technique was right because it stimulated the use of existing know-how and boosted "quality-mindedness" at a time when it was vitally needed. Most important of all, it capitalized on existing know-how.

As time went on, however, new diseases appeared. On certain days, almost all the operators seemed unable to control the machines satisfactorily, whereupon the defect rate would advance to 4-5 percent. At other times, certain individual machines went sour so that even the better operators could not run them. Moreover, it was noted that operators did not really understand how to make precise adjustments of the voltage; they frequently overadjusted and had to back off after running into trouble. It was becoming clear that the limit of existing know-how had been reached and that further prevention must come from the development of new know-how. The prescription was an intensive study of the innards of the machines.

Fourth Phase

The project is now in this phase. Already much has been done to develop better understanding of the process. Currents have been measured with ammeters, voltages with voltmeters, cycle times with electronic timers, electrode spacings have been gaged, uniformity of solder pre-forms has been scrutinized. Experiments with all of these variables included have been conducted to determine their influence on the quality of soldered joints. Results have not been so startling, since it must be remembered that the disease was one of sporadic flair-ups and their absence is harder to demonstrate than their presence. But certain chronic defects have already been virtually eliminated and what used to be considered "excellent" performance is now considered only "fair"

The objective in this phase is to reach the ultimate in defect prevention—the development of a set of standard operating conditions for the machines and measuring devices for certifying that the machines are operating at these conditions *before they are allowed to make parts for production.* Call this preventive maintenance if you like; it is part of defect prevention. It will certainly elimate much of what used to be classified as operator skill: what little skill factor remains will be the only residual cause for defects. The acceptance sampling plan at the machines will remain in force to keep tabs on that. While it is too early to know the results, it will be surprising if a level of less than 0.5 percent defective is not attained.

TOOLS AS PREVENTERS

The use of statistical quality control techniques, especially control charts, to diagnose and correct existing defect problems has been widely treated and is well understood. The preventive functions of these techniques have also been pointed out, but students of quality control do not always understand that the primary function of every statistical tool must be its defect-prevention function. It may be pertinent now to explore this viewpoint briefly, considering acceptance sampling, process capability analysis and control charts as the statistical tools of major importance.

ACCEPTANCE SAMPLING

Sampling plans are usually considered as having the primary purpose of protecting the consumer against accepting poor quality product. But the more use one makes of acceptance sampling, the clearer it becomes that the only real consumer protection comes from having the product made right in the first place. After all of our sage deliberations on probability and OC curves, we are forced to admit that the quality which will be accepted by a sampling plan tends to be pretty nearly equal to the quality that is submitted. Only in the event that a large amount of sorting is done can the claim of improved quality be substantiated and then it is doubtful whether a sampling plan should have been used in the first place. After all, 100 percent sorting is hardly sampling inspection.

The protection afforded by a sampling plan, therefore, does not come from its acceptance of lots but rather from its rejection of lots and from information which it provides for creating awarness of the process behavior. Recognition of these facts leads to three basic rules for utilizing the preventive function of sampling plans:

(1) Locate the sampling as close as possible to the production source so that a minimum amount of time is lost between the *fact* of making defectives and its *discovery.*

(2) See that the information derived from the sampling inspection is passed on in proper form to the "submitter" and see that it is used to locate troubles and prevent future recurrences

(3) Refuse to employ sampling unless the number of rejected lots will normally be few enough to act as a disciplinary measure to instigate action toward avoiding future rejections.

These principles have long been used in many quality control installations, particularly when the "submitter" and the "sampler" are

two departments of the same company. There is, however, increasing evidence that the same thinking is penetrating the consumer-vendor relationship and will ultimately prevail in this field. Inspired by the Hunter Spring Company, several companies now perform inspection close to the source of production and furnish inspection records to their customers. The increasingly popular Lot-Plot method of acceptance inspection has a built-in provision for furnishing copies of inspection data to the vendor. The U. S. Air Force Procurement agency is developing its policy of reducing inspection of product to a minimum and concentrating instead on auditing the vendor's means for controlling quality and preventing defects.

PROCESS CAPABILITY ANALYSIS

The analysis of process capability, through the use of the frequency distribution, the $\bar{X}$ and R chart, the simple X chart, or the Multi-Vari chart, [6] is a well-known and well-used technique for trouble-shooting. It can be a valuable tool in the defect-prevention program in two ways:

(1) The tackling of specific, troublesome factory problems inevitably sheds more light on the causes for defectives and hence automatically results in improvement for that particular product.[7]

(2) The cataloging and dissemination of capability data can give *all* plant personnel a new insight into many of their day-to-day problems and actually prevent many defect problems from ever arising.[8] In brief the process capability information can be used to help all of the people who contribute to final product quality to do a better job. It is self-evident that fewer defects are produced under such circumstances.

CONTROL CHARTS

It would be superfluous to dwell on the prevention benefits attainable through the use of control charts at the operating level. The conciseness and definiteness with which the chart tells an operator or set-up man to adjust at the first sign of a trend toward making defectives, or the laboratory technician when to add chemicals to the bath, or the foreman when to investigate and when to sit tight—all these and many other examples have been cited in the literature. It should be emphasized, however, that these defect prevention benefits will not generally be obtained unless it is first assured that the user of the chart actually knows the specific remedies for correcting the abnormalities which the chart may reveal.

SOME CASE STUDIES IN PREVENTION

The illustrations included with this article are six simple examples of the prevention philosphy at work in a variety of industries under a diversity of circumstance. Each story is necessarily brief, but it tells a poignant tale of recognition of the value of the preventive point of view. The author is indebted to his students at Northeastern University for the use of these studies; each represents the semester project of one of them. All company names are fictitious, but the instances are real.

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The Place of SQC in an Industrial Organization*

EDWIN G. OLDS

Carnegie Institute of Technology

IT is not my intention to present a fool-proof plan of injecting statistical quality control into your company. It is unlikely that any such universal formulation would be possible because the proper position of the statistical group depends so much on the organization and the executive personnel of your company, and because the success of SQC depends so much on the strength of the quality control engineer. However, I have a few ideas on the subject—very general ideas—which I have gained from experience, observation and very sober discussion of the matter with men, such as Professors I. W. Burr, C. C. Craig, L. A. Knowler, and M. E. Wescott who can give unbiased and intelligent opinions on the subject.

*This paper, in the main, is a transcription of a lecture given at Purdue University, on June 12, 1952, in connection with an advanced course in statistical quality control. Professor Irving W. Burr supervised the typing of the transcription and made some useful corrections.

THE CONTRIBUTION OF STATISTICS TO BETTER QUALITY

In the first place, how can the philosophy and methods of statistics serve your company in improving quality and reducing costs?

Your company, like all other companies who want to stay in business, keep a very close watch on the quality-cost ratio. Your interest, of course, is in making that ratio as large as possible. When we look at

the quality-cost ratio, Q/C, we perceive that the ratio tends to be made larger by an increase in quality or by a decrease in unit cost of good material which is produced, or by both changes working together.

Your company, of course, has quality control now. It is only necessary to look at the advertisements in various magazines to discover that companies have quality control, because they are very careful to state that fact. Actually, we have had quality control in existing companies more or less since those companies began operation. The company which does not interest itself in quality control of some sort will have great difficulty in meeting competition and will soon go out of business.

Some distinction should be made between quality control and *statistical* quality control. I like to define the latter as the application of *all* statisical principles and methods in the improvement of the manufacturing operation. Not all companies have *statistical* quality control.

What is this statistical philosophy to which I am referring? It seems to me that it is the recognition that every set of data represents a sample from a universe of data and that every decision rests on some inference regarding the unknown parameters of that universe. That is the story in a nut shell.

Why are statistical methods needed? Collection of data costs money, and so it is necessary to wring the maximum amount of information from the data we buy. Statistical methods are the most efficient methods for satisfying that requirement of getting the most for our money. Sometimes people having great discernment, long experience and lots of luck ring the bell without using statistical methods. Most of us are not in that class.

Professor Burr lists the following areas in which the statistical kit of tools is useful, if not invaluable, in effective decision making:

"1. Measuring consumer's wants
2. Research and development
3. Selecting the production processes or tools
4. Controlling production
5. Inspection
   a. Receiving
   b. Process
   c. Final
6. Inventory control
7. Market research
8. Accounting
9. Customer complaints
10. Shop experimentation
11. Executive control"

I find it tempting, but not practical, to pause for some discussion of the potential contributions of probability and statistics at each point. (Opportunities in connection with research and development, in particular, seem to be crying for greater recognition.) However, I take time only for the remark that, even when it is not feasible to apply detailed statistical techniques to all of the problems arising in the areas listed, still the discipline of statistics forces a person into a path of clear thinking, and this, in itself, is a contribution of prime importance.

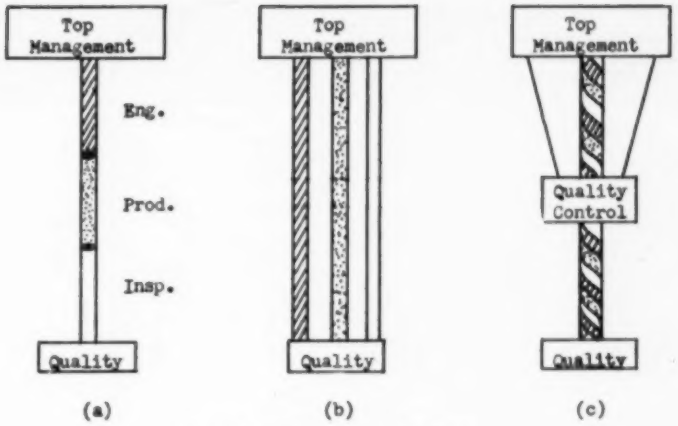

Figure 1 — **Designs for Quality**

DESIGNS FOR QUALITY

Having touched on the contribution of statistics to quality, suppose we consider the question, "What people, in your company, should be interested in quality?" This may cause you to ponder, "What people in my company *are* interested in quality now?"

Does labor have a stake in product quality? Is it important to labor that your plant continues operating —that it keeps the quality-cost ratio at a point such that you can compete with other companies in the field?

How about the stake of the clerical staff in product quality? Should they be interested?

The obvious answer is, of course, "Yes!"

But the natural leaders in the campaign for quality should be—must be—the supervisory and executive personnel. It is of almost paramount importance, then, that this group be concerned with the matter of quality.

It might be useful to sketch several possible designs for supporting quality in your organization. The first design might be pictured as in Fig. 1a. Top management, represented by the block at the top, delegates the responsibility for quality to engineering, which can be imagined as a strand of rope. The engineers give to production the design and method they consider necessary for good quality and say, in effect, "We've given you what you need. Now it's up to you!" So we knot on the production strand. The production men, in turn, take the position that their primary responsibility is quantity so they say to inspection, "We'll get the quantity out. Quality is your baby." So we have the inspection strand fastened on below production, and quality dangles at the end of the line.

The support for quality will not be strengthened by giving inspection the new name, "Quality Control." Inspection is only one function of a quality control division. Furthermore, it does not seem promising, in general, to operate quality control from the level at which the inspection group is located. A better design is suggested by Fig. 1b. Here all three divisions take their part of the load in parallel.

The second design, while stronger than the first, suggests an unfortunate separation which often exists between the three groups. Instead

of each operating independently, a close cooperation is needed for best results. Twist the three strands into a single cable, as in Fig. 1c, and the design is greatly strengthened.

Lest the strands untwist when a weight is suspended, we clamp the rope with SQC, a clamp which makes contact with engineering, production and inspection and helps them to work together. From this clamp there is a direct line to top management.

This last design, while somewhat crude and lacking in details, will serve to indicate my belief as to the guiding principles for building a strong support for quality. In my opinion SQC must take the lead in aggressive action to maintain and improve quality. It must be in a position to get and keep the cooperation of all three operating groups. It must have an independent connection to top management so that it can take action when necessary, without delay or interference.

My opinion that the director of quality control should report directly to a vice-president who is concerned with quality was voiced first in early 1944 at a course in statistical quality control at Los Angeles. There was considerable disagreement then, and there have been adverse arguments each subsequent time I have stated my views. If the time comes when engineering divisions are more generally directed by men with a thorough understanding of the principles and philosophy of SQC, the location of the function there may be feasible. Except in unusual circumstances I do not believe that a quality control director who reports to the superintendent of manufacturing or to the chief of inspection can operate with more than limited success. The former, having production schedules to meet, is primarily responsible for quantity and it is hard to serve two masters equally well. The latter seems to suffer the handicap implied previously.

It is unfortunate that so many attempts are being made to operate SQC from subordinate levels. That "Statistical Quality Control is one of management's sharpest tools" has often been said and should be more generally recognized not only outside the American Society for Quality Control but also by the members themselves.

CHARACTERISTICS OF A QC ENGINEER

Since, in the final analysis, the rating of a job depends greatly on the rating of the man who is doing it, we turn now to a delineation of a successful QC engineer. Eight quality characteristics will be mentioned, not necessarily in order of importance.

We might start with common sense, which, after all is fairly uncommon. Supposedly this is based on experience but, as some one has said, of the many people who have a particular experience only a few are able to properly interpret it. Perhaps common sense is the ability, first, to acquire knowledge, and, second, to know where and how to use it.

This brings us to the second characteristic, this thing called knowledge. The QC engineer needs "knowledge which is understanding, not merely knowledge which is recognition." He needs education, not merely training. Obviously he needs knowledge of SQC, but he also needs knowledge of his company and its products. He also needs knowledge of engineering and science. It is not absolutely necessary to be an engineer but, as has been remarked about the desirability of being slightly crazy if you work in Washington, "it certainly helps."

The QC engineer must work with people. Therefore, a pleasing personality is an important asset. It must go beyond being a "good mixer," because not only liking but respect must be generated. He must be able to exchange ideas and facts as well as funny stories.

It is necessary to be strictly honest, not only in the interpretation of data, but also in reporting results of quality control projects. The temptation to take undue credit for successes is hard to resist, especially at first when the methods are on trial. Much harm can be done, however, from the failure to recognize that benefits came only because others cooperated. If necessary, the man should err on the side of underrating his own contribution and be content to some extent, to take his reward in terms of satisfaction for a job well done.

The QC engineer needs imagination. I know many people who seem to have all the ingredients necessary for QC engineering except this matter of imagination. Those are the people who keep coming back and saying, "I can't get anything started. Could you make a suggestion as to where I should start? What should I do?" It's a good thing to ask for advice, but a man must think and reflect for himself. If he walks around with his mind and eyes open, the QC engineer who is interested in the applications of SQC will see statistical applications all over, not only in his work, but in his play, in his home. He'll probably worry his wife by running control charts on the time that she has dinner ready at night, or he may try to reconstruct her work week on the basis of statistical analysis. The latter, however, I do not recommend.

A QC engineer must have the ability and willingness to take the initiative. It is not enough to decide on a course of action. He must be a leader in making a start on it. There are many men in industry who, while they understand the first principles of quality control and can see points for useful application, hesitate to take the initial plunge. Others are not afraid to take responsibility even at the risk of being censured for making mistakes.

The man who wants to have continued success in applying statistical methods in industry must have a willingness to learn. How few people really do willingly learn! If you are willing to learn, you can find about you many, many opportunities. For example, in most industrial areas you will find courses being given which are open for your attendance. Some of them may not be concerned specifically with statistics or with SQC, but, nevertheless, are courses which will help you in connection with that function. At Carnegie Institute of Technology, for example, we have an evening course in statistical quality control, one evening per week, three hours; and credit in the course can be used in connection with work on advanced degrees. In the past, there have been in attendance at that course people who had to travel a hundred miles or more in order to get there. Also we have a course in probability and mathematical statistics which puts a theoretical foundation under the methods and techniques of SQC. In making such opportunities available, to persons who are willing to learn, my institution is not unique.

To experienced QC engineers, it seems quite unnecessary to mention the necessity for courage in the face of adversity. It's unusual for you to "make a killing" with the first job that you try. There is a fairly good

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chance that the first job that you think you ought to try, you will not be allowed to do. Or after you start to do it, you may find that you have simply run up against a stone wall as far as getting the information needed. Once in a while you will get breaks in that connection. But if it's necessary for you to have constant success in order to keep yourself working, then quality control engineering is not the field for you.

I have, at several conferences, cited this list of qualifications for a QC engineer and executives in the audience have said, "Those are the qualifications for a good executive. A man with all of those qualities can have almost any job he wants in my organization." That is the reason, of course, that we lose so many capable and efficient QC engineers to managerial posts.

To summarize it seems to me that the quality control engineer must be a *big* man; not a *little* man—not a *measly* character. It takes a *big* man to fill a *big* job.

OBLIGATIONS OF MANAGEMENT

Turning now to a discussion of the contributions of top management to a successful quality control program, we note, in the first place, that top management must be patient. It's not possible to order a "carload of SQC" for delivery yesterday. Many of the companies that, ten years ago, decided they wanted to have SQC in their plants are just beginning to reap the fruits of that intelligent decision. Statistical quality control should start slowly and build up gradually. At least a few successful jobs are needed before there will be any whole-hearted support for a plant-wide or company-wide program. Some of the companies that are reputed to have SQC in general operation would probably report "We have barely scratched the surface." In order that SQC be successful, many people in the organization, not primarily concerned with the operation of SQC, but in a position to make decisions affecting its proper operation, should at least know what it is and what it is trying to do. Otherwise their lack of understanding may seriously impede progress. The companies that have been most successful, it seems to me, are the ones which have recognized the need for providing education for such people all along the line; for the executive branch, the supervisory staff, and for union representatives.

The inclusion of the last group prompts me to digress long enough to answer a question occasionally asked me regarding the attitude of the union towards SQC. It has been my observation that, when intelligent union leaders find out what QC is, they like it. It is easy to see why. We are all familiar with the four M's which are ingredients of the manufacturing operation; Men, Machines, Materials, and Methods. The QC engineer recognizes this fact and, when there is trouble, endeavors to determine scientifically which one or which combination of those four factors is causing the trouble. Without SQC, the blame is usually placed on the man. American labor is willing to take the responsibility for its own mistakes, but it hates like blazes to be blamed when the difficulty is with a machine that everybody knows should have been replaced; or material that people say should not have been purchased; or methods which are antiquated, but cannot be changed until the person who devised them fifty years ago is ready to retire from the organization.

As a second requisite for success, management must give the quality control program several types of support. Obviously, it must be ready to back up the decisions of the Statistical Quality Group. It must hire good men as needs develop, as the program expands. Such men must be recruited outside the company unless suitable people already in the organization are readily available. Many a program is handicapped by a shortage of well-qualified personnel.

Top management must provide the tools, of course, such as gages, calculating machines, etc. It is very nice to find the accounting department with a battery of fully automatic desk calculators; but it looks very curious, then, to walk out into engineering and find the QC engineer having to get along with nothing more than a slide rule which he probably had to buy himself.

There is one kind of tool I want to mention particularly: Books. It shocks me, time and again, to find a company, which, although it expects to get first class work of a scientific nature from its technical personnel, nevertheless fails to provide them with adequate and readily accessible reference books and journals. *Industrial Quality Control* and the other technical magazines of that nature will be read avidly by the QC engineer, if they are put in his plant library, instead of in the home office sometimes a thousand miles away. As indicated above, the willingness to learn is an important characteristic of a good QC engineer. Top management has an obligation to foster this characteristic by providing the tools with joy, not reluctance.

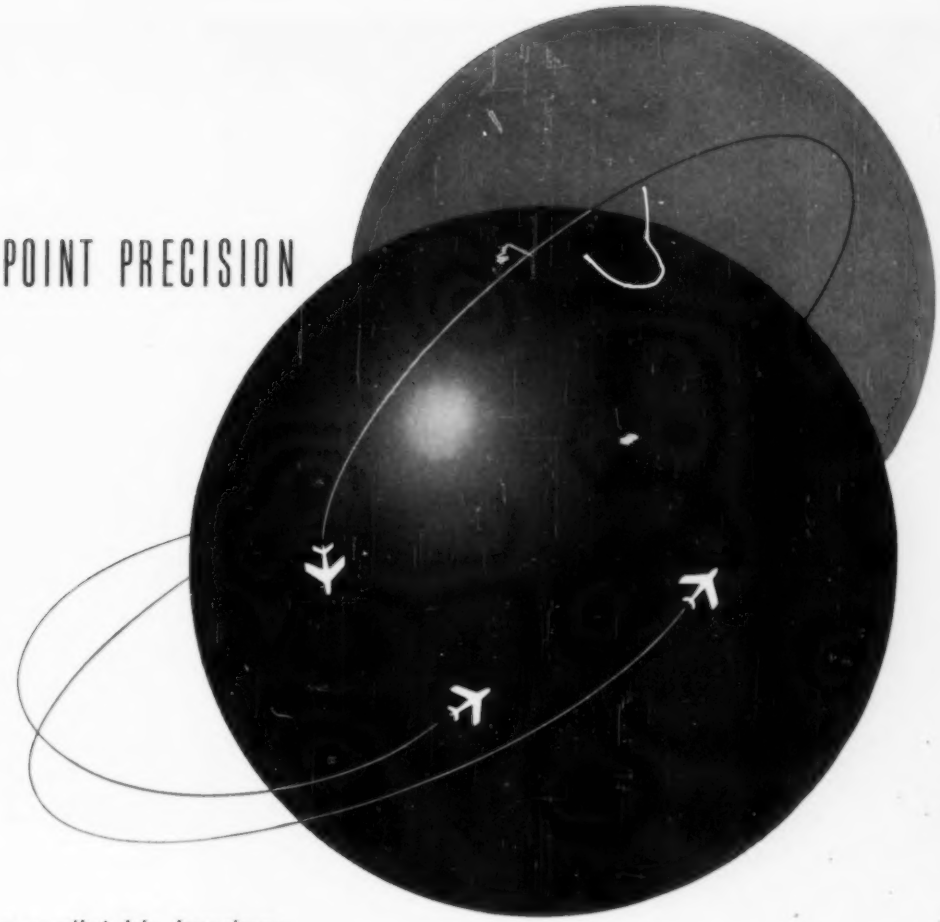
Like other pioneers the QC engineer usually works under somewhat adverse conditions. He is surrounded by an atmosphere of skepticism, if not active antagonism. He needs encouragement from top management. When he presents a report on a hard job well-done, there should be some one who will really read that report and offer a sincere word of commendation. While this obligation to offer encouragement based on genuine interest is mentioned last in my discussion of management contributions, its importance must not be overlooked. Otherwise success in getting and keeping a strong quality control organization may well be jeopardized.

In closing the previous section, I stated that the QC engineer must be a big man. As a final statement in this section, I offer the opinion that Statistical Quality Control is a program for a *big* company. I do not mean "big" in size, necessarily, but "big" in viewpoint. Perhaps the word, "enlightened," would express the idea more precisely.

CONCLUSION

The place of SQC in an industrial organization has depended in the past, and will depend in the future, upon both the QC engineer and the organization. The philosophy, principles and methods which belong to the field of statistics have, as I have indicated, much to offer to the problem of quality improvement. The design for quality which I have recommended places the statistical quality control division close to the chief executives of the company. Whether an individual company chooses to have its quality control division in that position will be determined by the importance of quality to the company and the extent to which the company executives appreciate the scope and potentialities of statistical quality control. Whether the statistical quality control division can hold that high a position depends on the caliber of the men who get the opportunity to do the work.

PIN POINT PRECISION



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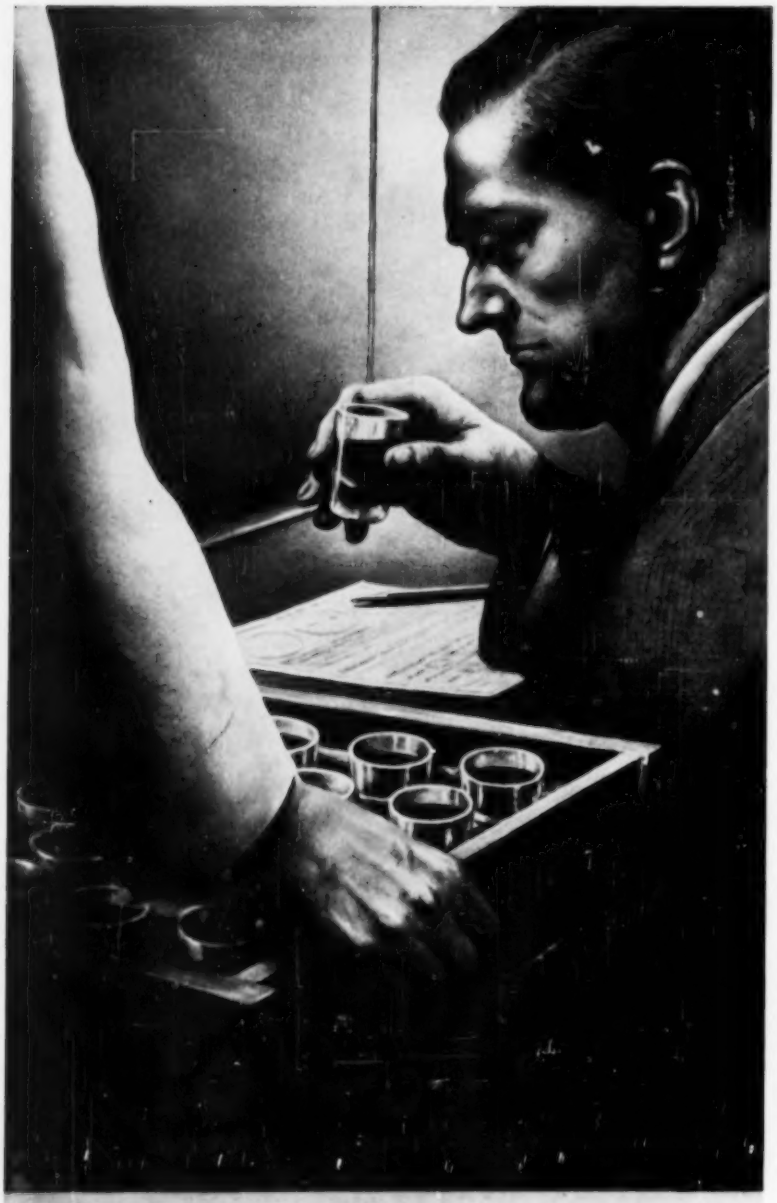

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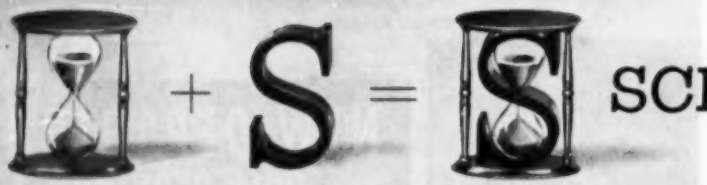

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Using Training Conferences as a Quality Control Catalyst*

PAUL C. CLIFFORD

State Teachers College, Montclair, New Jersey

THIS article really had its inception in a couple of comments made to me during the past year. One was at the annual convention in Cleveland. A friend, who was one of the real founders of the society, commented on the really impressive group attending that convention: "Paul, I wonder if this thing isn't growing faster than we are." The second comment occurred at a luncheon at one of the General Electric divisions where I was helping to conduct a conference. The general manager of the division asked me how industry was accepting quality control. I proceeded to repeat some of the "success stories" I knew. When I finished he said quietly, "Now I'd like to hear your explanation of the failures."

These two remarks caused me to do a little re-examination of conscience. I sat down to study my own activities in the field of quality control, to see what answers I could find to the questions implied or asked.

Five years ago the function of statistical quality control seemed to be the use of control charts and acceptance sampling plans by the inspection department. The typical organization chart, if it showed such a function at all, showed it as a minor appendage of the inspection department, consisting of two or three people concerned with acceptance sampling plans and control charts on parts or products. The leaders in the field of quality control did not agree with this limited concept, but in general that was the status granted by industry. Indeed even this limited status has not as yet received acceptance by a large part of American industry.

When quality control was considered as the application of statistical methods to the inspection function, there was an obvious need for training in certain fundamentals of statistics. To a great extent the program sponsored by the Engineering, Science and Management Training Program of the War Production Board met this need. Some 2000 people took the intensive course, and about 6000 more took part-time courses. Since the end of the war many thousands more have taken similar training sponsored by colleges, industries, or sections of ASQC. The content of these courses is well known and does not need restatement here. It was and still is difficult to evaluate these training programs.

I should like to give two quotations.

> "These training programs have been the subject for high praise and biting criticism. They have been criticized because they emphasized the mathematics at the expense of explaining usefulness of the techniques. This was a valid criticism. Yet at the time there were available too few people who had a shop background and who at the same time were qualified as instructors. The best source of instructors was in men of mathematical background. Moreover the mathematicians themselves began to learn shop needs, and the courses began to be more practical.
>
> Irrespective of these criticisms, these wartime training programs were the means for stimulating the imagination of thousands of men in many plants. The broadcasting of these seeds has grown, in record time, a crop of quality control enthusiasts. The influence of these men is beginning to make itself felt in industry."[1]

The second quotation gives another side of the story.

> "The usual experience, in these intensive courses is to find that initially, representatives from industry want and demand only so-called practical materials. After taking the course and making some use of their procedures, they learn the value of statistics and then decide that the difference between practice and theory is rather fuzzy, if a difference even exists. In fact, many take the view that what works in practice does so because it has a reason, and that reason is the theory. It is these 'practical' people who ordinarily request additional 'theoretical' work. In fact, they often ask that what might be a semester's or a year's work in mathematical statistics be presented during one forenoon, possibly in one hour; not only be presented but be set out in such a way that they can go back to their plant and use it in the particular problems at hand."[2]

As one of the "mathematicians who began to be "practical" I know that there is essential truth in both of these quotations. There is no doubt that a large proportion of those who have had basic training in quality control have never used the training. There is also no doubt that many have found the theory of statistics fascinating and have pursued it on their own. Purely as a personal reaction I would suggest that it is interesting to note how practical some of the professors have become, and how theoretical the engineers can get.

It is just about ten years ago that I taught my first class in statistical quality control. At the time it seemed very practical to me. In the course of the next five years I taught a great many such courses. The course content was similar to that of the standard texts. The class discussions were practical in the sense that most of them were concerned with problems and case histories, rather than with statistical theory. The persons enrolled came from a variety of industries, generally at the lower level.

Several years ago I began to wonder whether this work had been of real value, other than the fact that I was paid for it. I took the old class lists that I had and checked them over. I found that I could identify only a few who had continued any obvious connection with either statistics or quality control. I made an attempt to follow up on these ex-students of mine. I have by now checked up on a reasonable sample.

*Paper presented on the program of the Sixth Annual Convention of ASQC in Syracuse, New York, May 1952.

Not counting the large group who were temporary war-time employees, I find that they fall into three classifications.

The largest group by far are those who "found it interesting but we (the industry) never did anything with it and I've forgotten most of it." The second largest group of lost sheep were those who "transferred to another department" or "went to a new industry." There was a small group who were still doing quality control work, irrespective of change of industry or job.

Now in many ways this record is nothing to be ashamed of. I think it will stand comparison with the imprint left on your minds by many college subjects. There is in this case a different basis for evaluation, however. In general these people came to learn how to control quality; incidentally, how to use statistics to control quality, and not to learn statistics as an intellectual discipline. If my objective had been to teach the elements of statistical methods, I may have been a success. If it had been to help control and improve the quality of manufactured product, this looked like five years of failure.

Why had these people made so little use of what they had learned? Again I can suggest a long list of answers. But in general they come down to this: I had convinced them of the theory, and had given them some case histories. But I had not convinced their superiors, they had never gotten really started, and the shiny new tools had rusted away because they were never used.

I had done more harm than that. Many of the companies that sent young inspectors to such courses, had, mainly through lack of understanding of the aims and objectives of the program, severely handicapped them when they tried to apply these new and rather unfamiliar ideas. Many times the person achieved some success, such as getting a standard sampling plan initiated, after which progress stopped. Many people returned to their plants and reported: "It's a good theory but it would never work in this company."

Now the over all evil results of much of my teaching is this: Many companies today say that they tried quality control and found it did not work, or had very limited applications, where they have really not given it a trial at all.

Moreover I am sure that experience is not unique. Speaking at the convention last year in Cleveland, Dr. J. M. Juran stated: "In a recent paper[3] I reported on the results of quality control programs started since World War II by 39 companies. The study disclosed a shocking mortality rate for these programs. The failures were due to failure to utilize the managerial tools for quality control while at the same time overemphasizing the statistical tools." Juran finds that elements common to a successful quality control program are:

1. A clear program, spelled out in advance
2. Concentration on this objective, rather than on any *means* to that end
3. A high degree of managerial competence in the quality department
4. A high level of shop participation and cooperation.

The factors of adequate budget and technical competence of quality engineers were found to be of lesser importance.

This study by Juran is controversial. Quality control is defined as defect prevention, and a successful quality program is one that cuts the cost of defects by 50 percent. The company names, naturally, are not given, so that one is not able to judge how representative the sample is. Many would not accept this definition of quality control.[4] However debatable some of the assumptions are, I think that there may be general agreement with this conclusion: Too often our training efforts have concentrated on techniques, and neglected other elements necessary for success.

How can any training program attempt to meet these larger problems? I believe that the proper program can go a long way towards a solution, and that training conferences can really be a catalyst in getting a successful quality control program going. My remarks, in general, concern plant or company training conferences. Many of the ideas have grown out of a close association with Ellis Ott, with whom I have worked in the Rutgers Conference Series on Quality Control, and in various company programs.

First I should define what I mean by quality control. For this definition I shall use A. V. Feigenbaum's statement: "Quality Control is an effective system for coordinating the quality maintenance and improvement efforts of all groups in the manufacturing process so as to enable production at the most economic levels consistent with full consumer satisfaction."[5]

Notice that quality control thus defined is *not* the function of any small group in the manufacturing organization. It is a function that involves many groups at different levels. Purchasing, engineering, research, manufacturing, sales—there is not a single division in the company that is not interested in quality control. The management, the different departments, and the key personnel must have a clear understanding of the functions of a quality program, and a good grasp of the basic concepts behind this program.

One method of insuring this understanding consists in setting up a special committee for the quality control program. At Continental Paper such a committee consisted of the executive vice president, and the managers of research, engineering, manufacturing, sales, industrial engineering, and personnel. The function of this committee was to define the program, and to review periodically the progress of the program. Only after this committee had a clear understanding of the objectives, the functions and the basic philosophy of the program did we move ahead. Let me assure you that the committee members have become vitally interested in the program, and that the question of top level management backing has never had to be raised.

Next comes the question of shop participation. If quality control is as important as we believe, the program should not be started with inspectors. The plant managers, superintendents, chief engineers, general foreman and foremen are the people who can make or break the quality program. If they are convinced that a quality control program is going to benefit them, the battle is won.

How much time is needed in conferences for this level of supervision? Their time is valuable, they will resent its being wasted. I suggest that six to eight meetings of approximately 90 minutes each will do. If this seems shockingly little, remember the purpose is not teaching statistics but getting an understanding and appreciation of what quality control is about, and how it can

benefit them. This can be achieved in a short time, but only if we stick to certain principles.

The first principle is: *Keep it simple.*

The fundamental concepts of quality control are very simple. It has been a common experience that getting these basic concepts understood has been a difficult job in many industries. It is not my function in this article to present these in detail. Let me give an outline of a previous presentation.[6] The basic concepts might be listed as:

1. Any and all manufacturing processes exhibit variability.
2. There are two types of variability—chance or inherent variability, and variability that is assignable to specific causes that are economically worth finding and eliminating.
3. Inspection of a batch of finished product will distinguish between these two types of variability very inadequately.
4. Elimination or control of the causes of poor quality is the most important function of a quality program.
5. To control quality it is all important to reduce time in the manufacture-test-adjust cycle. To cut down this time element we must base our decisions on samples.
6. In general it is not possible to control a process by inspecting one or two sample items, classifying these as acceptable or defective.
7. The average of a small sample is much more sensitive to change in a process than are the individual measurements.
8. The range in a small sample can give a good measure of the inherent variability of a process.
9. A series of small samples can give a good estimate of process capabilities, as well as a good estimate of what it actually produced.
10. If quality data is worth taking, chart it, and use the chart for corrective action. If the chart does not lead to action, question the need for taking the data.
11. Inspection efficiency in routine 100 percent inspection is poor. Acceptance sampling of parts in process, and of final product, frequently will result in better quality.
12. Statistical techniques are a sensible tool to use in analyzing production and quality problems; they are not a substitute for experience and common sense.

The second principle is: *Keep it visual.*

Gadgets and models will enable a person to grasp a concept that hours of explanation will only confuse. Variability, both chance and assignable, may be demonstrated by a quincunx. Honest and crooked dice are even better for demonstrating the difference between the two types. Distribution models, with superimposed distributions of averages help the novice understand the principles of the control chart, as well as the inefficiency of attribute sampling.

Properly designed boxes of beads will demonstrate control of attribute measurements, and show the risks involved in acceptance sampling. Distribution models and sets of colored blocks show the combination of tolerances. A box of chips with the data from an actual process on them will demonstrate the difference between chance and assignable variability. Even such difficult topics as correlation and analysis of variance can be illustrated easily with three dimensional models.

The third principle is: *Avoid statistical terminology.*

This should be such an obvious principle that it is merely a question as to whether it can be achieved. I believe it can, and that no statistical terms except average, median, range, and frequency distribution need be introduced. I include the median because I find that a control chart for medians is much easier for the beginner to understand. For one thing, if all the points corresponding to individual measurements are plotted, and the median indicated by a different symbol, there is no confusion between control limits and specification limits.

The fourth principle is: *Keep to actual plant problems.*

It may be all right to tell about how quality control works in some other plant at the first meeting, although I would not. After the first meeting throw away the text book problems, and go get some data right off the production line. This must be planned for well ahead of time, in the sense of having the necessary personnel, equipment, etc. If possible get data that is fresh off the job right at the time of the meeting. This is the *big advantage* of an in-plant conference program. There should be no question of, "It's all right, but it wouldn't work here." By the time the course is over the method either worked or it didn't, but at least there is no question about it.

This is why I call these sessions training conferences, and why I want all interested groups represented. If a part can be controlled to 0.0003 in. and the specifications are 0.0005 in., we want the design engineer sitting in to tell us if it is economically worth producing these tighter specifications, or whether we can use modified limits to try and get increased production. If it is impossible to control the minor diameter of a cathode to the desired specification because of excessive variation in raw material, we want purchasing, engineering and manufacturing to take on the job of doing something about it. Let me assure you that all the various elements of a quality control program will come into the picture. Questions of inspection procedure, tolerance design, gage control, etc., cannot be avoided. In the last such conference I conducted, I requested the management to make just one requirement. Each person had to bring in objective data, with an analysis, on one quality problem in his division. By the end of eight meetings we were not discussing quality control — we were doing quality control.

The fifth principle is: *Keep it rolling.*

The plant personnel who attend such a conference have a host of other problems demanding their attention. Unless there is a planned follow up, the effect of such a conference will die. Quality control is dynamic and the problems of quality are constantly changing. The existence of the quality control committee gives an avenue for periodic review of the over-all program. Care must be exercised by the quality control manager on follow up, lest it be considered criticism by production and engineering departments.

It is here that the managerial competence of the quality control department head is most important.

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Avenues of communication on quality, must be kept open, not only from the top down, but also from the bottom up. The interest that has been aroused in the different departments must be nourished. But by now the the quality control program should be well defined, have the support of management, the understanding of objectives and procedures by other departments, a high level of factory participation and cooperation, and be on its way. Training conferences can really be a catalyst for quality control.

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Statistical Cost Control in the Paper Industry*

CARL E. NOBLE

Kimberly-Clark Corporation

INTRODUCTION

The role played by statistical methods in the control and improvement of product quality during the past ten years has surpassed all expectations. However, industry has been slow to recognize that these methods can be applied profitably to the study and control of most processes yielding measurements which are subject to variation. One of the most lucrative fields of application outside of quality control is that of cost control. Similar statistical problems face the quality control engineer and the cost accountant. Both collect large masses of data which are subject to variation. They need the help of statistical methods in recognizing errors in the collection, tabulation, analysis, and interpretation of these data.

The accountant is constantly being forced to answer the question, "How much deviation in standard cost should be a tolerated before taking action upon the process?" Seldom does a daily or monthly cost equal its expected standard. Variation not only occurs, but is expected. Yet there generally exists no accepted allowable tolerance. Statistical methods can make a real contribution to cost accounting by providing a scientific procedure of establishing reasonable tolerance limits. The accountant may also find the quality control chart a useful aid in a cost control system. This chart offers one of the best techniques yet found for presenting quality and cost data.

*Paper presented on the program of the Sixth Annual Convention of ASQC in Syracuse, New York, May, 1952.

SAMPLING AND MEASURING OF COST DATA

One of the important factors contributing to the failure of statistical methods to gain widespread acceptance in the paper industry has been the difficulty encountered in obtaining a random sample from the processes manufacturing rolls, skids, batch mixtures, etc. While this factor has been instrumental in discouraging the wide use of statistical methods, in reality it makes an understanding of these methods imperative if one is to control quality and costs more efficiently. Many times it is impossible to secure an unbiased sample in a roll of paper. The precision of an estimate based upon a biased sample can hardly be determined by judgment alone. The literature is filled with examples in which erroneous conclusions have been drawn about a population from data based upon a sample taken from only a segment of this population.† Even when both the sampling and measuring of an item are free of bias, the normal variation in the population (of say paper) and in the measuring techniques has to be understood in order to interpret measurements of the sample properly.

The discrepancies in quantities of raw materials consumed offer an example worthy of consideration. These quantities depend upon such items as pulp and paper moisture, proper proportioning of raw materials, consistency regulation, broke determinations, sewer losses, and estimates of in-process and other constantly changing inventories. The measurements of these items are not only subject to variation, but are quite prone to be biased at times. It is not uncommon for a raw materials discrepancy of $3000 or $4000 to appear at the end of a month in a certain operation. If a discrepancy of $4000 is reasonable in view of the normal variation in the sampling and measuring of the above mentioned items, then one of two steps should be taken:

(a) This discrepancy should be tolerated as an expected event and without too much commotion. Too often another $2000 is spent in a fruitless effort to find the cause of the discrepancy.

(b) More and better measurements should be obtained, usually at additional cost, to remove the possibility of such a large discrepancy occurring by chance causes alone.

When biases in the sampling and measuring systems are likely to introduce large discrepancies, it is generally wise to establish modest checks on these systems. For instance, the central laboratory might check daily one of the bales of pulp or rolls of paper tested for moisture by the regular testers. The control chart aids in interpreting the differences in results from the two independent tests. This procedure often proves easier and less expensive than searching for errors only after bias is suspected at the end of a month.

†Gallup, G. H., and Rae, S. F., *The Pulse of Democracy*, Simon and Schuster, New York, 1940.

TABLE I—**Pounds of Paper Waste by Shifts**

Shift	Days									
	1	2	3	4	5	6	7	8	9	10
A	89	112	121	91	75	86	123	98	96	97
B	99	108	106	117	79	105	106	100	83	114
C	115	132	103	98	81	93	105	114	87	124
$\bar{X}$	101	117.3	110	102	78.3	94.7	111.3	104	88.7	111.7
R	26	24	18	26	6	19	18	16	13	27

Such biases as those from operator carelessness disappear when the campaign is launched to find them. The real cause of the bias is never found. The installation of a modest check system upon a testing operation has not only supplied more accurate measurements, but has actually increased the tester's interest in his work. Too many testing jobs exist where there is no gage for evaluating the accuracy of work and in turn no real recognition of good work.

THE CONTROL CHART IN COST ACCOUNTING

Much time has been spent in emphasizing the necessity of securing the most accurate and reliable quality and cost data because the best methods of analysis, presentation and interpretation go to no avail if these data are inaccurate. With accurate data available one is in the position to make predictions and decisions about his operations. The control chart has been found most useful as an aid to operators and others in making decisions about product quality.

This chart can be equally valuable as an aid in making decisions about costs. The accountant needs the statistical approach for setting limits within which he can expect cost measurements to vary, even though the basic cause system producing these measurements remains relatively constant. There can be gained an understanding among those concerned that variation within these limits should generally be tolerated, but that a measurement outside these limits dictates that some action must be taken on the process. The method of calculating these tolerance limits is described with an example.

AN EXAMPLE OF CONTROL OF PAPER WASTE

The cost accountant is asked to set up a system for controlling waste in a certain department converting rolls of paper into sheets. The pounds of waste are recorded by shifts for a period of ten days as shown in Table I. The data are restricted to ten days in this example for simplicity. Actually, the data should cover at least one month or even three to six months if there exist suitable back records.

The average and range of the three shifts measurements during a day are represented by $\bar{X}$ and R respectively in Table I. The averages of the $\bar{X}$'s and R's are

$$\bar{\bar{X}} = 1019/10 = 101.9 \text{ and}$$
$$\bar{R} = 193/10 = 19.3$$

The central line on the control chart for X is $\bar{\bar{X}}$ and the 3σ control limits* for this chart are

$$\text{U.C.L.} = \bar{\bar{X}} + A_2\bar{R} = 101.9 + (1.023)(19.3) = 121.64$$
$$\text{L.C.L.} = \bar{\bar{X}} - A_2\bar{R} = 101.9 - (1.023)(19.3) = 82.16$$

The central line for the R control chart is $\bar{R}$ and the 3σ control limits are

$$\text{U.C.L.} = D_4\bar{R} = (2.575)(19.3) = 49.70$$
$$\text{L.C.L.} = D_3\bar{R} = (0)(19.3) = 0$$

The X and R charts are shown in Fig. 1. It may be seen that the R's lie well within the limits on the range chart, but one of the X's, is below the L.C.L. on the $\bar{X}$ chart. Ten samples are an insufficient number on which to base a reliable decision that a process is in satisfactory control. Caution should be exercised in projecting the calculated control limits to serve as limits for future control of the process, particularly when one of the X's is outside the control limits. After 25 to 50 samples have been recorded, then the control limits should be recalculated. If not more than one out of 35 of the X's or the R's fall outside their respective limits, then one can have considerable confidence that the process is in satisfactory control, and these limits can be projected and used as an index of control of future waste.

The process being in control means that the basic factors contributing to the waste (or any other cost figure) are relatively constant and that

*Theoretically, the probability is approximately 0.003 that a value will fall outside its 3σ control limits by chance alone.

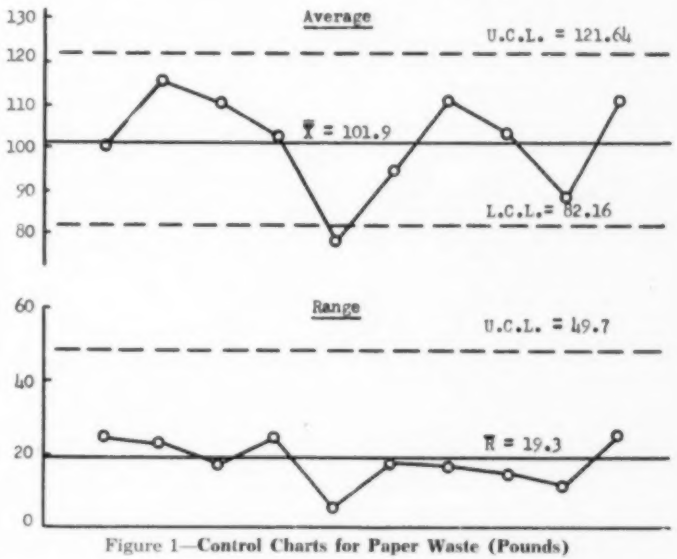

Figure 1—**Control Charts for Paper Waste (Pounds)**

variation in the actual pounds of waste is due only to chance causes—causes that either cannot be removed or cannot be removed profitably. Since variation in the actual waste is going to take place within the control limits even though the basic cause system remains constant, it is assumed that no change takes place in the basic cause system as long as the actual waste falls within the control limits. If an $\overline{X}$ or R falls outside the control limits, then this assumption is rejected and action is taken on the process to investigate the reason the basic cause system has changed.

When a standard number of pounds of waste per shift has been calculated over a long period of time and found to be reliable, the standard, $\overline{X}'$, rather than $\overline{X}$, is generally used as the center of the X control chart, and the control limits become $\overline{X}' \pm A_2\overline{R}$. If one wishes to plot the total number of pounds of waste for the day instead of the average number per shift, he multiplies the standard and the control limits calculated above by three to get the standard and control limits for the total waste during the three shifts. Finally, when the problem is that of setting control limits for the waste of the individual shifts, the standard deviation σ of the individual shift figures is calculated by dividing $\overline{R}$ by d_2. That is

$$\sigma = \overline{R}/d_2 = 19.3/1.693 = 11.40$$

The control limits are $\overline{X}' \pm 3\ (11.40)$ or $\overline{X}' \pm 34.20$. If $\overline{X}$ is used as the central line on the $\overline{X}$ chart, the control limits are 101.9 ± 34.20.

LIMITS BASED ON DAY-TO-DAY VARIATION

It is a good policy to secure a measure of variation, within the day, such as the range between the three shift figures, when the problem involves setting control limits for a daily cost. If the department or machine operates only one shift, then the production, waste, etc. may be recorded by one or two hour periods with the range between these periods being a measure of the variation within the day. However, in a great many situations the accountant obtains only one cost measurement a day (or a month) for a machine or department and he wishes to establish control limits for this daily measurement. A method of calculating these control limits is described with an example.

A particular department is expected to produce a standard number of container units per machine hour of operation. The deviations (called variances in cost literature) in the number produced from the standard are shown in Table II for 30 consecutive days.

These 30 daily measurements could be divided into ten subgroups of three each. By finding the range of the three measurements within each of the subgroups, one could proceed in somewhat the same manner as described in the previous example. However, the most successful approach in handling this type of daily measurements has involved the calculation of the ranges R of the consecutive daily measurements as shown in Table II. To check whether such R values could have come from a controlled process, the upper 3 σ control limit for these R's is calculated. This upper limit is

$$D_4\overline{R} = (3.268)(46.66) = 152.48$$

All of the R's in Table II are less than this limit. Furthermore, only one of the R's is above the upper 2 σ control limit [(2.512)(46.66) or 117.21]. Hence, it is reasonable to assume that the process is in good control. The standard deviation σ of the daily measurements is then estimated from the formula

$$\sigma = \overline{R}/d_2 = 46.66/1.128 = 41.4,$$

where d_2 is based upon a sample of size two. Since the average 2.30 of the 30 measurements differs only slightly from the standard of zero, zero is taken as the center of the control chart. The 3 σ control limits for these daily measurements are

$$\text{U.C.L.} = 0 + 3(41.4) = 124.2$$
$$\text{L.C.L.} = 0 - 3(41.4) = -124.2$$

The control chart in Fig. 2 shows these 30 deviation measurements along with the 3 σ control limits.

The 2 σ control limits have been found more acceptable in many of the cost control charts. This is particularly true where points outside the control limits may be investigated without too much effort. Furthermore, the method of using ranges of consecutive days often gives too wide control limits because these ranges are affected not

TABLE II—**Deviation in Number of Container Units Produced Daily**

Day	Deviation (X)	Range $\lvert X_t - X_{t+1}\rvert$	Day	Deviation (X)	Range $\lvert X_t - X_{t+1}\rvert$
1	−12		16	7	25
2	26	38	17	24	17
3	−36	62	18	5	19
4	−30	6	19	−3	8
5	34	64	20	−44	41
6	8	26	21	−45	4
7	34	26	22	1	46
8	−24	58	23	−12	13
9	40	64	24	18	30
10	−26	66	25	−27	45
11	69	95	26	−48	21
12	−38	107	27	−57	9
13	0	38	28	23	80
14	84	84	29	98	75
15	32	52	30	−32	130
	$\Sigma X = +69$	$\Sigma R = 1353$			
	$\overline{X} = 2.30$	$\overline{R} = 46.66$			

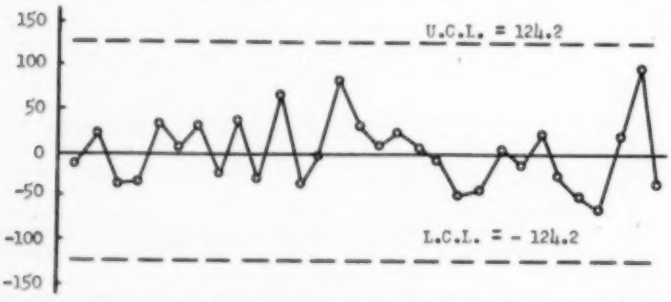

Figure 2—**Control Chart of Deviations in Number of Container Units**

WHAT'S THIS?

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One machine is accurately checking 8 dimensions simultaneously—separating correct, oversize, and undersize parts at a rate of 2100 an hour.

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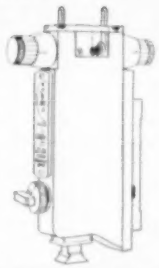
Eight, standard Sigma gauges, like this one: have been mounted together for rapid, accurate inspection of mass produced parts. Each gauge, accurate to within .00005", measures one dimension. More (up to 30) or fewer gauges could have been used, depending on the number of dimensions to be checked. These gauges, with standard Sigma mounting units, and special fixtures where necessary, can be set up to inspect parts a fraction of an inch long, or several inches long, a foot, or longer.



Depending on the arrangement, they can check internal and external diameters, length, depth, or other characteristics. The type of parts and the method of feeding determine inspection rates—hand feed: up to 600/hr.; semi-automatic: up to 900/hr.; fully automatic: up to 3500/hr. or more. Gauges are quickly and easily set to required tolerances and change-over from inspecting one type of part to another can be done within 10 or 20 minutes.

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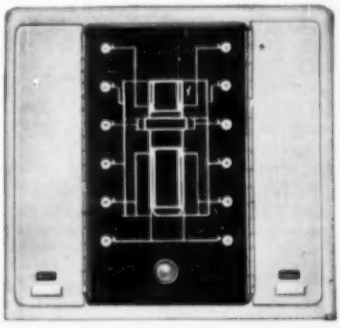

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only by chance variation, but also by real shifts in the level of the basic cause system from day to day. Thus, the probability of a measurement falling outside the 2 σ control limits is usually less than 0.05, approximately the probability normally associated with 2 σ limits. The fact that these ranges may include real shifts in level of the basic cause system necessitates that a careful job of rationalization be performed upon the data. That is, those data covering the period when an abnormal portion of the ranges fall outside their 2 σ or 3 σ limits should be removed and a new R calculated and used as the basis for the control chart limits. The rationalization is further complicated if the ranges are taken over three or four, rather than two, consecutive days since a shift in the level of the basic cause system is more likely to occur. When the ranges and, in turn, the process are hopelessly out of control, it is necessary to get the process in a state of control before calculating the control limits. Little confidence can be placed in control chart limits based upon data collected from an out-of-control process.

APPLICATIONS OF COST CONTROL CHARTS

The measurements shown in Table II are typical of such cost measurements as those for production, waste, labor, raw materials discrepancies, maintenance, research, and others way too numerous to mention. The measurements may be on an hourly, shift, daily, or monthly basis. In any case the control chart approach provides a scientific manner of obtaining the limits within which a cost measurement can be expected to vary.

The establishment of limits for monthly cost can greatly aid in the interpretation of these costs. However, there are two serious weaknesses in too much dependence upon monthly cost analysis for control. The first is the delay factor which might involve waiting until the middle of the following month to learn that an operation fell below standard the first part of a month. The second factor is that monthly costs often cover a heterogeneous set of operations over many days, machines, and crews and typify none of the actual operations. It is difficult both to find the cause of high costs and to place responsibility for them. For these and other reasons,

(a) place control charts in the production departments where they can be observed by the operators

(b) let each point on the charts represent a particular operator's or crews' efforts and represent as small a unit of production as practical

(c) place the points on the chart as soon as possible

(d) let the charted points represent units, such as pounds of waste and rolls of paper, which are meaningful to the operators.

Experience in quality control has shown that there is no way yet found for bettering the control chart medium of presenting data. Yet, the cost accountant may find it an unsurmountable task: to place on the control chart all the figures on his pages of cost sheets. In such a situation he should consider calculating the control limits for these figures and recording a figure on his cost sheet in (say) red, blue, or green according as it is above the upper control limit, within the limits, or below the lower control limit respectively.

CONCLUSION

This article encourages the cost accountant in the paper industry to use statistical methods to aid in the interpretation of cost data. These methods can give him much needed insight into the biases and normal variation in his sampling and measuring systems. The control chart is recommended as a powerful aid in controlling and minimizing costs.

Probability Statistics Applied To Tax Returns*

A. C. ROSANDER

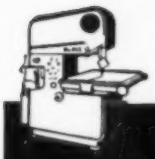
George Washington University and Bureau of Internal Revenue, Washington, D. C.

ONE of the major sciences that can be applied to solve quality control problems is probability statistics. Whether we are using sampling inspection, or statistical quality control, or design of experiments, or analysis of variance, or correlation analysis—we are applying the principles of probability statistics. It is no accident that this science is so closely identified with quality control. This is because it is a methodological science whose applications are bound to have quality implications.

In the current practice of statistical quality control, interest lies in the quality of the physical object produced; this is natural since the goal of factory managers and engineers is production. To the statistician however, the physical product is the end result of a significant quality-building process. Probability statistics helps build quality into an object because it builds quality into data, quality into decisions, and quality into performance. It does this by substituting probability sampling for judgment sampling, by controlling biased error instead of ignoring it, by using efficient methods of estimation instead of off-the-cuff methods, by employing design of experiments instead of traditional practices, by using effective methods of interpretation instead of rule-of-thumb, by designing the entire inquiry instead of doing each part in isolation from the rest. This is why probability statistics is such a powerful and versatile science when applied to the problems of research and management.

Statisticians do not yet know the full range of application of probability statistics to the problems of management; apparently what has been done to date has only scratched the surface. Experience shows us however that it can be applied in the office as well as in the factory, to production as well as to research, to service operations as well as to factory operations, to finance as well as to manufacturing, to persons as well as to machines. The big determining

*Paper presented on the program of the Sixth Annual Convention of ASQC in Syracuse, New York, May 1952. The statements made herein, with the one exception noted, are those of the author and hence are not to be interpreted in any way as official pronouncements of the Bureau of Internal Revenue.



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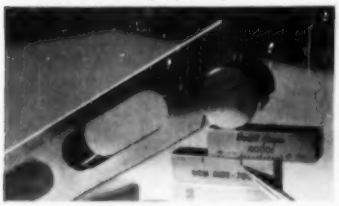

ments of 10 micro-inches. Nominal height of the set is .700", but one surface of each block is tapered. The height increases as the upper block is moved to the right, decreases as it is moved to the left. The amount of change is indicated by 10-micro-inch graduations on the upper block as shown in the illustration. Price is available upon request.

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The expendability of gage blocks is considerably reduced as there is less wear, although their use is greatly increased. The gages are wrung together by the *moderate pressures* of the holder clamps so that there is no distortion due to squeezing. The wear caused by rubbing action when gage blocks are wrung manually is entirely eliminated. Assembly in the holders minimizes the chance of dropping the blocks or otherwise damaging the measuring surfaces. The blocks do not contact the work being checked, the End-Standards take over this function.

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factor is not what is traditionally called the subject matter of the problem, but whether the solution of the problem in whole or in part can be found in the frequency distributions of key characteristics."[1]

It is not surprising therefore to find that probability statistics is being used to solve the problems of a tax agency like the Bureau of Internal Revenue. There are several possible areas of application. In the first place, the Bureau is charged by law with the responsibility of compiling annual statistics on income and taxes from various forms filed with the Bureau. When the base of the individual income tax was broadened, and as the number of business concerns grew steadily, the number of tax returns increased tremendously. Individual income tax returns now exceed 52 million, corporation returns total nearly 700,000 while partnership returns of income are close to 1 million. With such a large number of returns to process, the use of a probability sample instead of a 100-percent tabulation becomes a necessity.

A second area of application concerns the audit of tax returns. Clearly it is a physical impossibility for the Bureau with its present staff, or even with a much larger staff, to audit every tax return every year. From the beginning the Bureau has used judgment sampling grounded in experience, as the basis of its regular audit program. Within recent years the question has arisen as to what role probability sampling might play in the Bureau's audit program.

An audit program calls for the use of probability sampling on a person basis in order to discover those who should file a tax return but do not. Since the usual audit system is based upon filed tax returns, it is obvious that the taxpayer who never files a return is never going to be subject to audit. The use of a probability area sample which gives every individual in an area such as a city or county an equal chance of being selected, provides an efficient way of finding out how large this problem is, where it is concentrated, and whether the error discovered is worth the cost of discovering it.

The third area of application lies in various verification and review functions not included under audit. One of these is the verification of punch cards, another is the review of investigative work, another is post audit, another is verification of coding operations, while still another is the verification of calculations and bookkeeping operations.

A fourth area of application is the control over the variability of the performance of personnel: clerical workers, card punch operators, typists, calculators, investigators. The control over the variability of the performance of an investigator for example might start in the training course, and certification of competence might be based upon whether his performance on simulated tax cases came within tolerated limits. Periodic checks could be undertaken to insure that variability in the field is also under control.

A fifth area of application is for the purpose of special operating studies. Often it is necessary to design a probability sample for the purpose of a quick one-time study for management purposes. We may want to make an estimate of a characteristic which we do not have; we select a random sample from a file. We may want to test how closely certain workers in the field are following a procedure; we select a random sample of their work. We may want to know how a retail price change compares with a tax change such as that on beer and spirits; a nation-wide probability sample provides the answer.

Still another area of application is found in the use of probability sample surveys of taxpayers, for the purpose of measuring attitudes toward taxes and tax forms, and for the purpose of measuring the effectiveness of a tax education program. It is also possible to design field tests for the purpose of testing the relative effectiveness of two or more different forms to be used in filing on a given tax. Thus far no applications of probability sampling in this field have been made.

DESIGNING A SAMPLE FOR STATISTICAL REPORTS

In designing a probability sample to take the place of a 100-percent tabulation for annual statistical reports, it is necessary to design a sample which will give estimates with a sampling error no larger than that prescribed, and with no higher frequency of occurrence than a specified probability.

The problem can be illustrated by determining how large a simple random sample would be required to meet the following specifications:

a. The relative sampling error p in the estimated mean or aggregate is one percent.

b. The probability of getting this deviation from the mean must be no more than five percent. This corresponds to a normal deviate x' with a value of two.

c. The coefficient of variation cv of the basic tax or income characteristic being estimated, such as net income or deficit, is two.

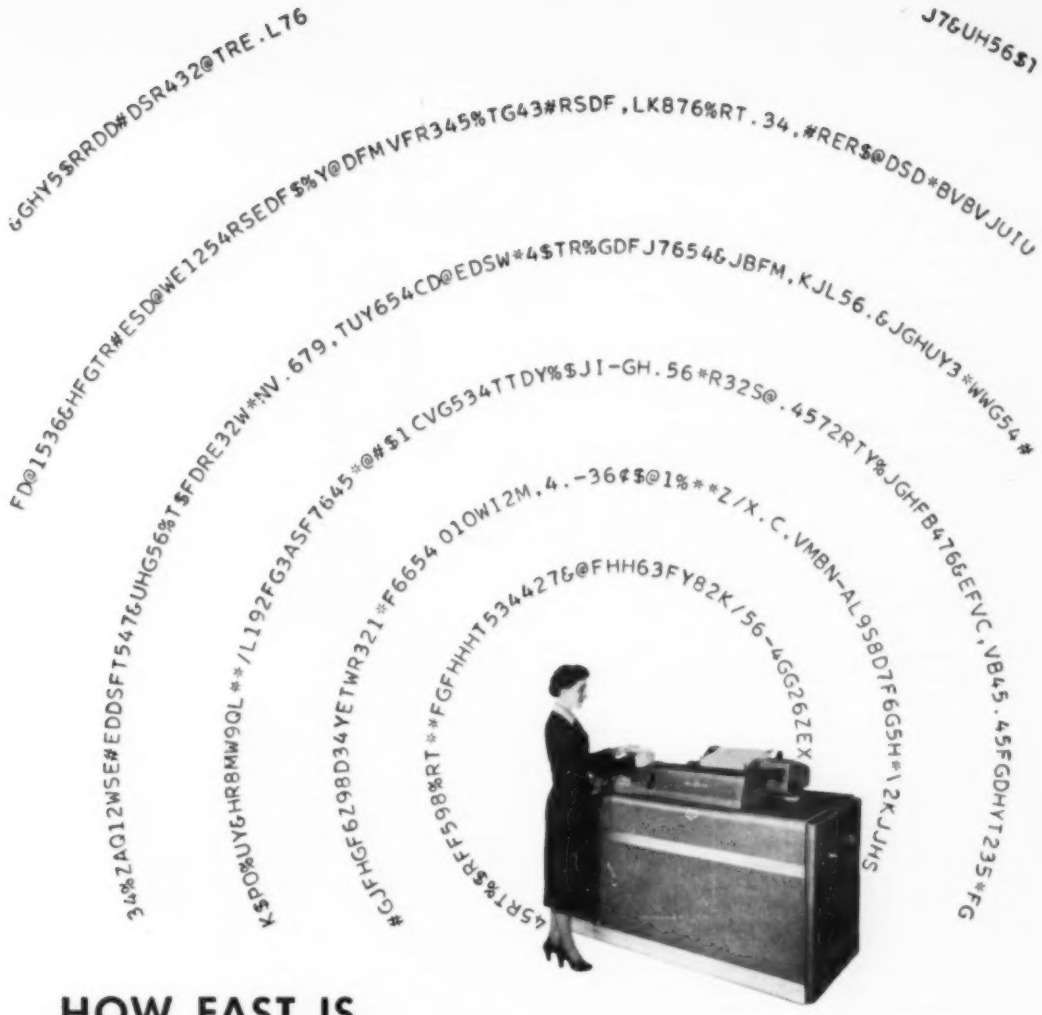
Two other conditions have to be met: Sampling must be from an infinite population, and the mean or aggregate must be normally distributed. The size of the random sample required is 160,000 and is calculated as follows:

$$n = \frac{x'^2\,(cv)^2}{p^2} = \frac{2^2 \times 2^2}{.01^2} = 160{,}000$$

In other words, it would be quite possible to obtain an adequate estimate of this characteristic by drawing at random only 160,000 returns from the population of 52 million returns, or by using only about 0.3 percent of the total.

In actually sampling individual income tax returns, we do not use this sampling plan for a number of reasons. We know that stratifying the population by size of adjusted gross income, by type of return, and by business and nonbusiness return, will greatly reduce the variability of basic estimates. This means that stratification will improve the precision of our estimates. On the other hand, income tax returns are assembled for administrative convenience into bundles of 100 returns, so that the bundle can be used as a sampling unit. However unless the returns are thoroughly mixed before being assembled into bundles, the use of the bundle will give estimates with higher sampling variances than will the use of the same number of returns selected at random without regard to the bundles. Furthermore estimates on relatively rare characteristics, and for relatively small sub-groups of taxpayers, are usually required so that a sample of 160,000 returns is too small.

The actual sampling rates for the various adjusted gross income strata into which the individual income tax returns were divided for the years 1949 and 1950, are as follows:



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Adjusted gross income	*Sample rate—%* 1949	1950
Under $7,000	0.5	0.3
$7,000 to $25,000	10	10
25,000 to $50,000	25	25
$50,000 and over	100	100

In 1949 a sample was selected on a bundle basis for returns with an adjusted gross income of less than $25,000; it was selected on an individual return basis for returns with adjusted gross income of $25,000 and over. Furthermore, for the group with adjusted gross income of less than $7,000 a one-percent sample of business returns was selected in order to obtain adequate statistics for this group. In 1950 the sample was selected on an individual basis; for those bundles with adjusted gross income under $7,000 the sample consisted of the first return in every three out of ten bundles, while for those between $7,000 and $25,000 the first ten returns in every bundle were selected rather than every 10th bundle, as in 1949. This sample plan for 1950 resulted in a total sample of 680,000 returns, or about 1.3 percent of the total population of about 52 million returns.

In a similar way it is possible to design probability samples of corporation income tax returns, and partnership returns of income. A corporation sample that will give adequate estimates of most characteristics for most of the more common subclasses requires about 100,000 returns or about 15 percent of the population. This design calls for stratified random sampling based upon the individual tax return, not the bundle, as the unit of sampling. A fairly high proportion of the population has to be used because in order to get adequate estimates by subclasses the largest corporations have to be sampled 100 percent—anywhere from the largest 10,000 to the largest 25,000 returns depending upon one's purpose. Even so, a tremendous amount of paper work is eliminated by using probability sampling instead of a 100 percent tabulation.

A method has been devised which allows a probability sample of tax returns to be selected as these returns are moving past some processing point in the tax agency.[3] This method, which features the use of punch cards and sampling boxes, not only provides a way of selecting a stratified random sample but gives complete control over the sampling selection operations. Furthermore the method is efficient and flexible so that it can be inserted into a routine of operations without causing any bottlenecks. This method was developed jointly by the Bureau of Internal Revenue (BIR) and the Federal Trade Commission (FTC) for the purpose of drawing probability samples of corporation income tax returns for 1949. The estimated population, the sampling rate, and the size of the samples, by size of corporation, are given in Table I.

TABLE I — **Probability Samples of Corporation Income Tax Returns—1949**

Asset size class ($1,000)	Estimated population*	BIR sample† rate	BIR sample† number	FTC sample rate	FTC sample number	Total sample number
Unknown‡	57,000	1:15	3,800	1:10	5,700	9,500
0-50	235,000	1:90	2,600	1:60	3,900	6,500
50-100	98,000	1:30	3,200	1:20	4,800	8,000
100-250	97,000	1:18	5,400	1:9	10,800	16,200
250-500	43,000	0	0	1:7	6,100	6,100
500-1,000	25,000	0	0	1:4	6,200	6,200
1,000-5,000	27,000	0	0	3:5	16,200	16,200
5,000 and over	10,000	0	0	1:1	10,000	10,000
Totals	590,000		15,000		63,700	78,700

*Active corporations filing a corporation income tax return.
†The Bureau of Internal Revenue restricted its sample to that portion of the population with assets under $250,000 and with no balance sheet.
‡Some returns do not have a balance sheet, or the balance sheet is incomplete.

Some comments are relevant to this sample design. The principle of optimum allocation was used to allocate the sample to the different asset-size strata. The sample for the Bureau was designed on the basis of an estimated population of 485,000 returns; actually this number turned out to be about 507,800 so that the sample size obtained was somewhat higher than the 15,000 aimed at.

A probability sample of partnership returns of income can be designed to meet similar requirements for estimates. Assume that we have 950,000 returns, and that the largest 25,000 are included 100 percent; that leaves 9,250 bundles of 100 returns each. Now let us assume that the selection of one return per bundle is sufficient for the job at hand. That means a total of 9,250 plus 25,000 or 34,250 returns. If the size of a bundle is 100 and the average variance within a bundle is 52, and if we sum over 9,250 bundles, then the standard deviation of the estimated total for this design is $(9{,}250 \times 100^2 \times 52)^{1/2}$ or 69,354. Since the mean is estimated to be five per return, the estimated aggregate is 4,625,000. The relative sampling error then is 69,354/4,625,000 or 1.5 percent. Actually the error will be less than this because the area sampled 100 percent (which has no sampling error) accounts for about one-third of the total income. This means that the actual sampling error for the grand total is two-thirds of 1.5 percent, or about one percent.

If random samples of five are taken from each bundle, then the standard deviation of the estimated aggregate is $\left(\frac{9{,}250 \times 100^2 \times 52}{5}\right)^{1/2} = 31{,}016$. The percent error in the sampled area is 31,016/4,625,000 = 0.67 percent. For the grand total the error is about 0.46 percent. Actually the gain in the precision of the estimates is not proportional to the increase in sample size; however this is the price one has to pay in order to improve the precision of estimates of characteristics of small classes and rare items. In this latter case the total size of the sample is 25,000 + 46,250 or 71,250 returns.

From this discussion of sampling design it is clear that probability sampling compared with 100 percent tabulation represents a very sharp reduction in the amount of paper work involved in processing and in handling these returns, without any very serious loss in information. Indeed if the probability sample is that of audited returns, we may find that the data from the sample are more accurate because the bias in unaudited returns may average higher than the sampling error due to random selection of audited returns.

DESIGNING A SAMPLE FOR AUDIT PURPOSES

Probability statistics including probability sampling can be used in audit work for a number of different purposes. In the first place, by audit we mean careful examination of the tax return of a taxpayer; in one kind of audit this examination is carried out by mail or telephone without

Why so fussy about a fence row?

MORE than once Harry has been chided for the pains he takes lining up a fence row. With all the precision of a navigator he sets the course of that fence, and he doesn't let it vary an inch. You can see him out there, directing the placement of each single post, his eye sighting along the row with the accuracy of a marksman.

To those who kid him about being so fussy, Harry offers some cold logic. It's true, says Harry, that it isn't always necessary to have a fence row just so—that, as long as a fence is strong enough to hold back stock and straight enough to separate fields, it'll do. But, he says, being particular is a kind of habit with him, and making exceptions whenever it's convenient might spoil him—might break his good habit and make it tough to be particular when it *is* necessary.

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directly contacting the taxpayer, while in another type of audit there is an actual examination of the taxpayer's books and records.

Probability sampling may be used for purposes of estimation, for purposes of selecting cases for audit, for purposes of checking or reviewing audit work, for purposes of sampling inspection. It may be used therefore both to control the errors of the taxpayer, and to control the performance of the investigator.

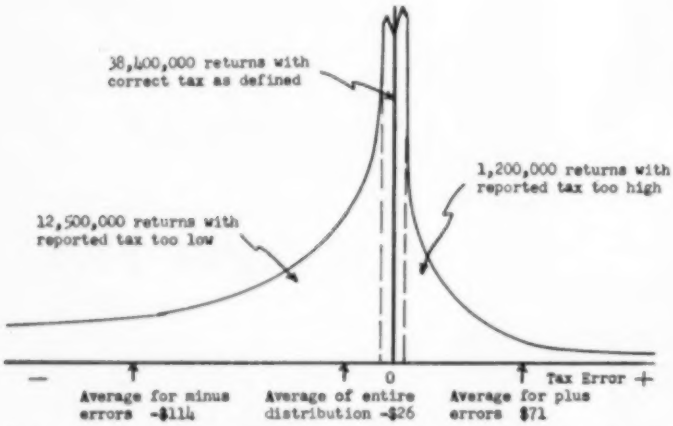
38,400,000 returns with correct tax as defined
1,200,000 returns with reported tax too high
12,500,000 returns with reported tax too low
—
0
Tax Error +
Average for minus errors -$114
Average of entire distribution -$26
Average for plus errors $71

Figure 1 — **Characteristics of the Distribution of Tax Error Based on 1948 Individual Income Tax Returns**

In order to get the maximum benefit from the audit sample program, it is necessary to obtain high quality data; this is done in the following ways: the entire program is carefully planned, the sources of bias are controlled, relevant data such as the number of hours spent on examining each sample return are collected, probability sampling is used, and the data are subject to statistical analysis.

One of the most obvious uses of such an audit sample is that of defining the problem of noncompliance— its magnitude and extent— and to indicate where to concentrate audit resources for the purpose of correcting the most tax error per man-hour of investigation. A probability sample of 160,000 returns was selected from all individual income tax returns filed in 1948, and estimates made therefrom for the entire population. The major findings which were released to the public by the Bureau in May 1951, are as follows[2]:

1. About one out of every four individual income tax returns is in error relative to tax.
2. The total amount of tax error made is about 1.5 billion dollars.
3. Of the number of returns with tax error, 90 percent are in favor of the taxpayer, while ten percent are in favor of the Government.
4. The 1.5 billion dollars of tax error was made by taxpayers reporting $7.4 billion. The total tax reported by all taxpayers was $15.5 billion.
5. The average amount of tax error increases steadily as income increases.
6. The frequency of tax error among business returns is about twice that among nonbusiness returns.
7. The major source of tax error is unreported or under-reported income. Personal deductions and exemptions are other major sources of error. Arithmetic errors made on the tax return are a distinctly minor source of tax error.
8. The frequency distribution of individual income tax error based on these data, is a highly peaked, highly skewed distribution. (Fig. 1).

In this probability sample, the number of hours required for the investigation of each return was recorded, and used to obtain a ratio of the amount of tax error corrected per man-year. Estimates of this ratio were obtained for a wide variety of classifications of taxpayers— by type of tax return, type of business, type of tax error, size of refund. From these estimates it was possible to determine what kinds of returns to select for audit in order to correct the maximum amount of tax error per man-year of investigation. The relating of man-hours to tax error has been very illuminating and productive.

Probability sampling for audit purposes is being applied to both individual income tax returns and to corporation income tax returns. The audit sample for individual income tax returns is a subsample drawn at random from the random sample used for statistical purposes. The first audit sample included about 160,000 returns, but later audit samples have been smaller with more emphasis on sampling business returns. A major purpose of these probablity samples is to provide estimates which can be used to point to the most productive areas of audit examination—to the types of returns which can be readily identified and which result in the maximum amount of tax error being corrected per man-hour of examination.

The probability sample of corporations for audit purposes was limited to a population of about a half million corporations most of which had assets under $250,000 because this area lends itself more readily to a feasible sampling program. This sample was drawn from the 1949 returns on a stratified random basis, and consisted of about 16,000 returns. The field work on this sample has been completed, the tabulation is well under way, and some preliminary results are now being obtained. It is planned to use this sample to define the problem and to indicate where the maximum amount of tax error can be corrected with a minimum amount of manpower.

The initial design of these audit samples could not be very good technically because of the almost complete lack of any knowledge of the frequency distribution of tax error. As we gain more knowledge about the characteristics of tax error, we shall be able to design much more effective probability samples. We shall always be limited, however, by the fact that the coefficient of variation of tax error, is relatively high compared with that of most economic

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and industrial characteristics (that is the standard deviation of the distribution is high relative to the mean, sometimes being three or four times as large as the mean). Much depends however upon whether we shall be able to find one or more bases of stratification which are effective in accounting for the variability of tax error.

APPLYING SAMPLING TO TAX AUDIT

Suppose that it is proposed to use random selection as one basis for choosing filed income tax returns for the purpose of a field audit or investigation. The question arises as to how effective such a plan would be. It is possible to throw some light on this question by direct application of a simple principle of probability statistics, providing that the problem is restated as follows: What is the probability that a taxpayer will be selected 0, 1, 2, . . . times during his tax lifetime, if the selection of the taxpayer is random, and the sample thus drawn is a certain percentage of the filed returns?

Assume that we have 52 million tax returns filed annually, and that the present tax system continues indefinitely. Assume that we draw repeated random samples of 1, 3, 5, and 10 percent from this population of tax returns. The probability of anyone being drawn as the first sample element is one in 52 million, or 0.0192×10^{-6}; the probability of being drawn as the last element of a one-percent sample is one in 51,480,000 or 0.0194×10^{-6}. The probability of being the last element drawn in a ten-percent sample is one in 46,800,000 or 0.0214×10^{-6}. For all practical purposes the probability of selection is constant.

In this problem it would be possible to work out various answers depending upon how many years there are in a tax lifetime, a value which could vary all the way from one year to about 70 years. For the present illustration we shall take 45 years as an estimate of average tax lifetime. On the basis of these statements we can answer the question in the following way. The probability of a taxpayer being selected 0, 1, 2, 3, . . . 45 times during his lifetime is given by the successive terms of the binomial $(Q + P)^{45}$, where P is 0.01 for a one-percent sample, 0.03 for a three-percent sample; 0.05 for a five-percent sample, and 0.10 for a ten-percent sample. The probabilities of being selected a specified number of times for each of these four possibilities, are given in Table II.

TABLE II

Number of times selected	Probability of occurrence			
	1% sample	3% sample	5% sample	10% sample
0	.636	.254	.100	.009
1	.289	.354	.236	.044
2	.064	.240	.273	.107
3	.009	.107	.206	.170
4	.001	.035	.114	.198
5 or more	.001	.010	.071	.472
Totals	1.000	1.000	1.000	1.000

These figures show that the probability of not being selected at all decreases from about 64 percent for a one-percent sample to about one in 100 for a ten-percent sample. In other words, we have to select a ten percent randon sample in order to reduce to a very small amount the probability of not being selected at all during an individual's lifetime. In order to do this we have to increase the average number of times from about .01 x 45 or 0.45 for a one-percent sample, to about 0.10 x 45 or 4.5 times for a ten-percent sample.

The probability values given in this table are based on 45 years; for those who pay taxes for more years the chances are higher that they will be selected at least once; for those who pay taxes for fewer years the chances of being selected are less.

Unless a tax agency audits about ten percent of the tax returns selected on a random basis, the probability of escape during a lifetime is very high. Many agencies may find such a sample size prohibitive.

It should be emphasized that this is a simple example of how probability statistics can be applied to analyze a problem. An even more important consideration than the probability of escape is the fact that since about 75 percent of the returns are free from error, simple random selection results in drawing an excessively large sample from those with acceptable tax returns, a sample which is largely though not completely wasted. A more effective way is to isolate groups of taxpayers where the probability of tax error is high and to concentrate the sample in that area. In other words the principle to follow, so far as it is possible and feasible to follow it, is that of sampling groups of taxpayers with probabilities proportional to the magnitude of the tax errors made.

ANALYSIS OF VARIANCE FOR DESIGNING SAMPLES

Finally, we wish to add a note on how analysis of variance can be used for designing probability samples. This technique can be used in several different ways: it can be used to test the effectiveness of stratification or subdivision or classification in removing or explaining variation. It can be used to obtain unbiased estimates by eliminating the effect of certain factors or components. It can be used to test how much is lost or gained by using a group sampling unit instead of an individual element as a sampling unit. It is this latter use we wish to describe.

Until recently the Bureau has been using bundles of 100 tax returns as sampling units. The bundles were easy to handle, fitted in with the regular administrative procedures, and there was little or no loss over simple random sampling due to the fact that the returns were fairly well mixed before being bundled. However recent developments have led to a departure from this method of sampling. There is a growing tendency in Bureau operations to physically segregate various kinds of returns before bundling—by type of return, by problem case, by business and nonbusiness, and in many other ways—so that the bundles represent more and more a stratification of the population. It was recognized that under such conditions, the use of the bundle as a sampling unit would mean an increase in the magnitude of the sampling variation to which the estimates were subject. An earlier application of analysis of variance to a random sample of 140 bundles of 1947 partnership returns of income selected from 35 districts, led to a similar conclusion relative to the use of bundle sampling of partnership returns. The summary of this analysis is given in Table III where the key variate used is net income or deficit.

Attention is directed to the mean square of each component. There is

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a highly significant difference between districts so that stratification by this factor would be effective. There is also a significant difference between bundles within districts indicating that there is some additional variation which would not be eliminated by the stratification by districts.

What this analysis suggests is the use of bundles, not as sampling units, but as strata. If this is done then the best estimate of the population standard deviation is $\sqrt{52}$, or 7.2. For a random sample of 100 returns this would mean a standard error of estimates of 7.2110 or 0.72 compared with a value of about 1.1 if bundle sampling were used, a very significant reduction.[4]

References

1. For a discussion of the broader aspects of the problem see A. C. Rosander, "Quality Control Through Probability Statistics, "*Industrial Quality Control*, November 1951, pp. 34-36.

2. A. C. Rosander, R. H. Blythe, Jr., and D. W. Johnson, "Sampling 1949 Corporation Income Tax Returns," Journal of the American Statistical Association, June 1951, pp. 233-41.

3. "The Audit Control Program — a Summary of Preliminary Results," United States Treasury Department, Bureau of Internal Revenue, Washington, D. C., May 1951.

4. For a description of this method see A. C. Rosander, *Elementary Principles of Statistics*, D. Van Nostrand.

TABLE III

Component	Degree of freedom	Sum of squares	Mean square
Between bundles	139	16.735	120.4
Between districts	34	9.168	269.6
Between bundles within districts	3	265	88.3
Interaction: districts x bundles	102	7.302	71.6
Within bundles	13.517	698.446	51.7
Totals	13.656*	715.181	52.4

*The bundles averaged about 97 returns rather than 100; this difference is not of any significance.

Control Charts May Be All Right, But —

FRANK PROSCHAN

Statistical Engineering Laboratory, National Bureau of Standards

Dau Ting Thomas, daughter of an American missionary to Hong Kong, seemed uneasy.

"Stat, as you know, I've been given the job of setting up and maintaining control charts at the plant. Now, I have my doubts about the whole business. I'd like to ply you with questions until I'm blue in the face."

Stat smiled, "Start changing color."

"In the first place, Stat, I imagine you need to know a great deal about higher mathematics and statistics to set up these statistical control charts and to keep them going. Isn't that true?"

"How are you on arithmetic, Dau? Can you add, subtract and multiply? If it were a matter of life and death, could you divide?" Stat kept a straight face.

Dau Ting Thomas smiled wryly, "Of course, Stat. Anyway I have a calculating machine, so that's no problem. But honestly, Stat, is simple arithmetic all that's required?"

"Yes, Dau, a high school graduate should have no trouble setting up and maintaining statistical control charts with the proper instructions. Next question."

"Look, Stat, why do we have to keep a chart when the quality variable is always well within specs? I should think we'd be perfectly happy to know that the values we're getting are miles below the spec."

Stat S. Titian always carried a copy of Plato's *Dialogues* in his coatpocket, so that he was well versed in the Socratic method.

"Dau, if a man knew he could increase the quality of the product his company was producing, reduce the costs of production and increase the knowledge and control of the process, should he be concerned with how close or how far the quality variable is from the spec?"

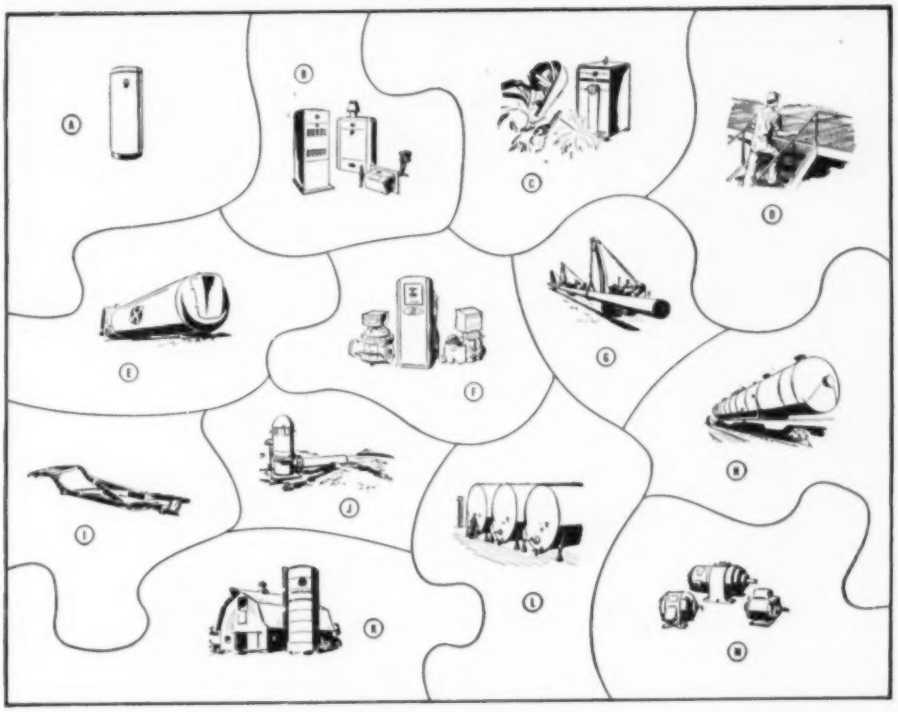
"No, of course not, Stat. If a man (or a woman) could attain all those desiderata with no ill consequences, I would be the first to encourage him to do so."

"Encourage yourself, Dau, for you are that man! Oops, pardon me— that woman. You see, it has been the experience of many plants that by keeping control charts (with follow-up action) on important variables quality of product improves, cost of production drops, and knowledge and control of the process increases regardless of where the spec happens to be located. Next question."

"Stat, isn't it true that control charts have been applied mostly to industries producing large numbers of individual items, like nails, pencils, tiles, etc., but have not been applied to the chemical industry to any great extent?"

"It is very true, Dau, that statistical quality control methods were first applied to mass production industries turning out large numbers of discrete units. But it is equally true that these same methods are being applied with success and profit to the chemical industry. As a matter of fact, these same statistical control charts are being applied successfully to such diverse fields as mass production industries, chemical and drug industry, paper industry, laboratory tests and analyses, and clerical operations. You see, the method is perfectly general and may be applied wherever it is desired to control a repeated operation."

"But I have another idea, Stat, I've been told tnat the reason why this particular process shows so many shifts in level and so many points outside of limits is that the raw material fed into the process changes.



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Now if that is the case, what can you do with such a process—you're limited by the raw material."

"If it can be demonstrated that the composition of the raw material is a factor in determining the quality of the final product, then your statement is perfectly valid. However, I'll bet you dollars to doughnuts that this same statement is made in many, many cases where it isn't at all true. Actually, the smart thing to do, Dau, is to determine by actual experimentation, perhaps, for what variables the raw material does determine the quality of the product and for what variables it does not. As a matter of fact, the control chart can be a very useful tool in making such determinations. Let me warn you, Dau, that if you're going to maintain these charts and use them to try to improve the production process, you have to be very careful about believing any such objections. You'll find that such objections will be put forward simply because it's the easiest way out."

Dau pursed her lips thoughtfully. "What you're saying, Stat, is that if a man thinks it's going to be troublesome and difficult to find the cause of these out-of-control points, he will find it a lot simpler to attribute them to the cause over which he cannot exercise any control because that makes life a little easier for him."

Dau fished among her charts, drew forth one that looked like a much milder case of measles (she circled the out-of-control points in red) than most of the other charts in her possession. "Look, Stat," she explained, "here is a chart where things are pretty much under control. Why should we continue the chart on this particular variable? It's under control."

Stat smiled, "Why continue paying insurance when you have succeeded in staying alive for a number of years so far—get the analogy?"

Dau nodded, "In other words, just because a particular variable has stayed in control for some time doesn't guarantee that it will remain that way forever. I guess it would be a form of insurance to take measurements every so often and keep a chart so that we can tell if any new disturbing cause enters the process."

Dau Ting Thomas seemed to accept this explanation, but, like in the Greek legend, with each doubt removed, two new ones sprang up.

"Stat, you've answered all my questions thus far, but I still have a few that might be a little tougher to answer. For instance, as I understand it, one of the main purposes of the control chart is to tell the engineer when a product of unusually good or unusually bad quality is being produced. Now, we know about unusually good or unusually bad quality products without keeping a statistical chart, simply because we know how things are running. When anything out of the ordinary occurs, the lab tells us of it. So why the need for control charts?"

Stat had a ready response. "I grant you that such a system might work, but would you claim that it's the most sensitive system? Is there any objective, rational criterion which permits the lab to decide when the observed variability is excessive and due to a cause, and when the observed variability is just the natural, normal variability of the process under study."

Dau was forced to yield ground. "No, I don't believe there's any objective, rational basis to it at present. I guess that would be desirable. But if these statistical control charts have an objective, rational basis, how about tellings me what it is?"

"Certainly, Dau. Control limits are calculated for each control chart based on the past experience of that particular process. These limits are so determined that if the manufacturing (or laboratory) process remains stable only 3 points in 1000 will fall outside of these limits. This would imply that when a point does fall outside of limits, there's a probability that some cause is operating, since it's so unlikely to be due to chance."

Dau seemed to be about out of questions. Suddenly she jumped up. "Stat, I'll bet the workers will resent this sort of device. Why they'll think it's a way of checking on them. The whole plant's liable to close down tomorrow as the result of a strike!"

"Easy now, Dau. If you were a worker at a machine, say, and you had a chart sitting right by the machine telling you how things were going, would you be happy or sad about it?"

"Come to think of it, if I were at all interested in my work, I'd welcome the opportunity to improve the quality of my work. I guess, a worker would rather be the first to know if the product he's turning out isn't so hot. If it's his fault, then at least he has a chance to correct the trouble before he learns of it the hard way."

Dau Ting Thomas seemed convinced by this time that the control charts were worth trying. She thanked Stat and left.

Several weeks later Dau Ting returned with some completed charts under her arm.

"Stat, look here are some control charts that I've been keeping. I thought you said only 3 points in 1000 would fall outside of limits. Yet on some of these charts it's more like 300 in 1000 points that are outside of limits. How come?

Stat was forced to smile at Dau's naivete. "Don't you remember I said that only 3 in 1000 points would fall outside of limits *if* no causal factors entered the process. Obviously in this case where 300 out of 1000 points fall outside of limits, there must be causal factors entering the process all the time."

Dau Ting's face fell. After picking it up, she said, "Gee, that's terrible. I'll get the plant engineers to look into this process pronto. I thought I must have made some mistake in my calculations.

"Stat, now look at these charts. For these variables, the process begins out of control and seems to stay out of control. Now, what's the use in continuing these charts when, judging from past experience, these charts will only show continued lack of statistical control. In fact wouldn't it be better not to put in black and white the tragic history of some of these process variables."

Stat had heard many unusual and tortuous arguments in the course of a long and illustrious career, however this last assertion revealed to him anew and frailties of the human mind. Patiently he explained, "Dau, in the first place if *action* (first, investigative; second, corrective) is not taken immediately when points go out of control, then, as you say, there is little reason for maintaining these charts. But you see, the whole point in setting up and maintaining these charts is to use them to tell you when the process is not doing as well as it could be doing, and then to take corrective action. Your second statement concerning the disadvantages of putting into the record for everyone to see the fact that a process is not stable and is not doing as well as it could makes me shudder. Obviously if one has done one's best and the process stays out

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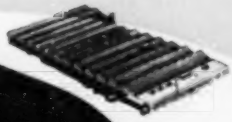

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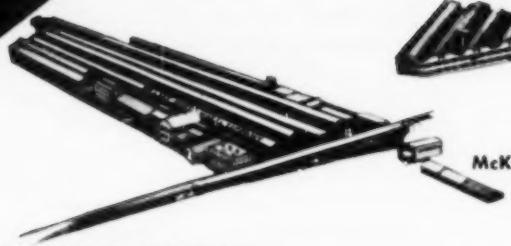

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of control in spite of it, one should not be ashamed of letting everyone see this. On the other hand if improvement is possible then one should make it."

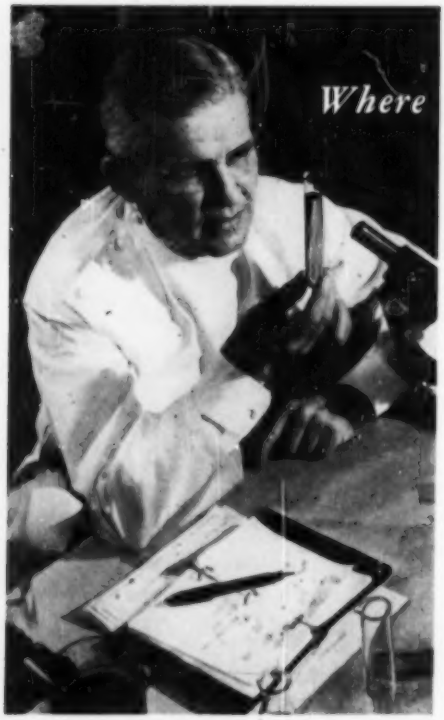
Dau smiled sheepishly, "You're right, Stat, of course. But, here's a question that one of the executives asked me. The density, he said, is an extremely important variable. Looking at your chart, I see it's under control but why couldn't we simply narrow the control limits and then investigate the reason for the points going outside of these new, more narrow limits. Maybe that way we could reduce the variability of product density some more, thus putting out an even finer product than at present."

Stat rubbed his nonexistent whiskers before replying, "Offhand that does seem like a reasonable proposal but actually it won't work. Here's why. Suppose you were to narrow the control limits to $\frac{1}{3}$ of the conventional width, it can easily be shown that by chance 32% of the points will fall outside of these new narrow limits. If you then investigate the cause for these points falling outside of limits, you would almost always make no appreciable improvement in the process. Another way of stating this is that the points falling outside of these narrow limits are actually displaying no significantly greater variability than the points falling inside these narrow limits. You'd be doing just as well to investigate the points inside the narrow limits as the points outside. When you're considering the variability of points within the conventional three standard deviation limits, you're dealing with the natural normal variability of the process and you're batting your head against a stone wall in practically all cases if you try to reduce this normal process variability without making basic changes in the actual process, i.e., change process equipment, use different raw material, etc."

Dau thought her next question would really stump the expert. "Stat, you know that the chemical analyses made to get these values that go on the charts are held up for a week at a time because of the laboratory workload. Now, how can a plant engineer figure out the cause of the out of control point when a whole week has gone by? It seems to me that the value of the control chart is diminished tremendously in such circumstances."

Stat nodded agreement. "Absolutely right," he said. "In order for these charts to be used effectively the values must be plotted *currently*. Let me ask you this, though, Dau, would it be possible for the laboratory to analyze $\frac{1}{2}$, $\frac{1}{3}$, maybe even $\frac{1}{10}$ of the present number of samples and complete the analyses of these samples the same day, or perhaps a day or two later? You see the advantage? All that's needed is a random sample of plant product. There is no point to knowing the value of every specimen produced by the plant. What is needed is speed not completeness."

Dau rose to her feet. "Stat," she exclaimed, "you've been very helpful to me. To be honest with you, I came to scoff, but I shall remain to praise—statistical control charts, long may they live!"



Where LIVES depend on quality control

In pharmaceuticals, as in nothing else, too much of a good thing—or too little—can be disastrous. With few exceptions, a drug's potential for good is directly matched by its potential for harm in the event of misuse or error.

In the manufacture of antibiotics and specialized pharmaceuticals, Bristol Laboratories enforces a rigid system of checks and counter-checks at every step—from the receiving platform to the shipping room—to assure unvarying consonance of composition with label specifications on each of its many products. There can be no compromise—a human life may depend on it.

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We're turning out hundreds of other varied products for home and industry —from cellophane tape to lithograph plates! In fact, we've even got a couple of things that are so unique we haven't found a way to use them yet!

Is it time for us to settle down? Not on your life! We're still looking for new business fields worth entering. We always will be. But to continue our growth we must continue to lead. And that means we must always lean heavily on strict quality control. Whatever the product, we demand of ourselves—and deliver to our customers—the high quality that *precision* standards assure.

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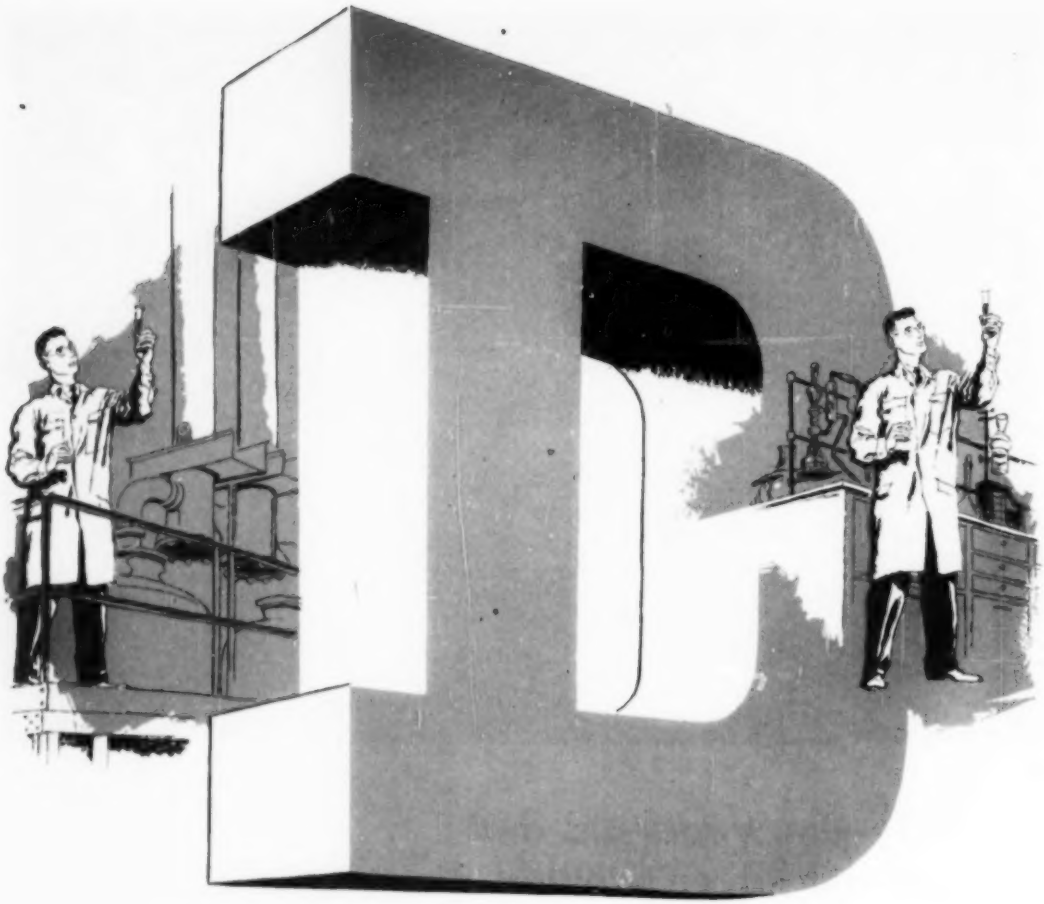
3M COMPANY



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7th Annual ASQC Convention

Keynote Address by Philadelphia's Man of the Year

F. N. Piasecki

Frank N. Piasecki Chairman of the Board of Directors of the Piasecki Helicopter Corporation, world famous pioneer in the development of the tandem rotored transport helicopter, will be the keynote speaker for the 7th Annual Convention of the American Society for Quality Control.

He received his education at the University of Pennsylvania and the Guggenheim School of Aeronautics of New York University, after which he founded the P. V. Engineering Forum Inc., which is now known as Piasecki Helicopter Corporation. He flew the second successful helicopter in America and developed the world's first successful tandem type, transport size helicopter as well as a new 40 passenger model, soon to fly.

Mr. Piasecki was the first pilot to qualify with the C.A.A. as a helicopter pilot, without first being licensed to fly airplanes. He is a founder of the Twirly Birds; an Honorary U.S. Coast Guard Helicopter Pilot; a Fellow of the Institute of Aeronautical Sciences; Past President of the American Helicopter Society and Past Chairman of the Helicopter Council of the Aircraft Industries Association. He is also a member of the following groups: NACA Sub-Committee on Helicopters; Society of Automotive Engineers serving on the Helicopters, Cockpits and the Blind Flying Instrument Committees; the Advisory Committee, Guggenheim School of Aeronautical Sciences of N.Y.U.; the Institute of Aeronautical Sciences; Professional Engineers Association (Philadelphia Section); Helicopter Association of Great Britain; Society for Non-Destructive Testing; American Society for Quality Control; Engineer's Club of Philadelphia; Wings Club of New York; Board of Trustees of the International House of Philadelphia; Aircraft Industry Advisory Committee of the O.P.S.

The more famous honors Mr. Piasecki has received include the following: National Junior Chamber of Commerce Award as one of the "Ten Outstanding Men of the Year" (1952), as well as Philadelphia's Junior Chamber of Commerce Award as Philadelphia's Outstanding Man of the Year (1951); appointment as a member of the Industry Consulting Committee of the National Advisory Committee for Aeronautics; a recipient of the Lawrence Sperry Award of the Institute of Aeronautical Sciences for 1951; Delegate to the Joint International Conference of the Institute of Aeronautical Sciences (U.S.A.) and the Royal Aeronautical Society (Great Britain). He established the Dr. Alexander Klemin Award as the highest honor in rotary wing aeronautics from the American Helicopter Society.

The Piasecki Helicopter Corporation is a leader in the field of Quality Control in the Aeronautics Industry. They have established an intricate and very efficient system of insuring the highest product quality of the helicopters produced. The Society is indeed fortunate in having Mr. Piasecki open the 7th Annual ASQC Convention.

Convention Committees

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PROGRAM HIGHLIGHTS 7th Annual Convention of The American Society for Quality Control

SCHEDULE OF EVENTS

WEDNESDAY, MAY 27, 1953

8:30 a.m.	Registration—Convention Hall
8:30 a.m.	Exhibits open—close at 5:30 p.m.—Convention Hall
11:00 a.m.	Opening Assembly—Convention Hall
	Speaker—Frank N. Piasecki, Chairman of the Board of Directors, Piasecki Helicopter Corp., Morton, Pa.
12:15 p.m.	Luncheon—Convention Hall
2:30 to 4:30 p.m.	Technical Sessions—Convention Hall
4:35 p.m.	Annual Meeting—American Society for Quality Control—Convention Hall
9:00 p.m.	Social evening—Crystal Ballroom—Benjamin Franklin Hotel

THURSDAY, MAY 28, 1953

8:30 a.m.	Registration—Convention Hall
8:30 a.m.	Exhibits open—close at 5:30 p.m.—Convention Hall
9:30 to 11:30 a.m.	Technical Sessions—Convention Hall
12:15 p.m.	Luncheon—Convention Hall
2:30 to 4:30 p.m.	Technical Sessions—Convention Hall
6:30 p.m.	Annual Banquet—American Society for Quality Control—Crystal Ballroom—Benjamin Franklin Hotel

FRIDAY, MAY 29, 1953

8:30 a.m.	Registration—Convention Hall
8:30 a.m.	Exhibits open—close at 5:30 p.m.—Convention Hall
9:30 to 11:30 a.m.	Technical Sessions—Convention Hall
12:15 p.m.	Luncheon—Convention Hall
2:30 to 4:30 p.m.	Technical Sessions—Convention Hall
6:00 p.m.	Convention Closes

GENERAL INFORMATION

Convention Headquarters—Benjamin Franklin Hotel
Luncheons—Convention Hall, catered by McCallister
Technical Sessions—Convention Hall
Annual Banquet—Crystal Ballroom, Benjamin Franklin Hotel
Social Evening—Crystal Ballroom, Benjamin Franklin Hotel
Ladies Headquarters—Lafayette Room, Benjamin Franklin Hotel
Plant Tours—Ford Motor Co., The Budd Co., Quartermaster General Testing Laboratory
Refreshments—Courtesy of Cocoa Cola, Inc., (Booth 68, 69)
Information Booths—Benjamin Franklin Hotel, Hotel Adelphia, Convention Hall

at Convention Hall • Philadelphia, Pennsylvania

PHILADELPHIA—Birth place of the Declaration of Independence, television, all steel automobile bodies, streamlined trains, first capitol of the United States, site of the first library, the first university, the first hospital, the first suspension bridge, plays host to the SEVENTH ANNUAL CONVENTION OF THE AMERICAN SOCIETY FOR CONTROL. Transportation of all types will carry you in, out and around Philadelphia. The large number of hotels and restaurants will make your stay enjoyable. Transportation direct from hotels to Convention Hall will be available at a very nominal charge.

EDUCATIONAL PROGRAM will include for the first time advanced statistical techniques, their application, shortcomings and advantages. The five periods of two lectures each will cover: sampling, "F" test, measures of variation, "t" test, required sample size, Latin squares, analysis of variance, 1, 2, 3 and 4 factors, correlation and regression, both simple and multiple.

EXHIBITS—Plans for the largest number of exhibitors yet seen at any American Society for Quality Control Convention have been made. Many gage and inspection equipment manufacturers will display their products. Local and national industries will show how Statistical Quality Control helps them build and sell better products. This is an opportunity you must not miss as it will be invaluable to you and your company.

LADIES PROGRAM—The elaborate program that has been planned includes coffee or tea and cookies in the morning to be served in the Lafayette Room of the Benjamin Franklin Hotel; hostesses to plan shopping tours; Valley Forge Historical Tour on May 27th at one p.m.; a luncheon and style show of summer clothes and apparel, by The Jeanne Trulick Shop.

SOCIAL EVENING—Entertainment, refreshments and group singing will be included in a gala event long to be remembered by all.

BOOK BOOTH—Books on Quality Control and related subjects will be on sale at booth Nos. 70, 71, 72. Many authors will be in attendance to discuss and autograph the various books on sale.

PLANT TOURS—They will present a broad picture on the subject of Quality Control and Statistics: the Ford Motor Company will show how they assemble automobiles and control incoming material; The Budd Company will exhibit the production methods used on their famous stainless steel streamlined train and the automobile chassis assembly lines; the Quartermaster Depot will show its clothing factory and its General Testing Laboratories. Space is limited; reserve it early. (For the Quartermaster Depot bring proof of citizenship.)

PROCEEDINGS will be available for holders of tickets as indicated on registration form. Additional copies will be available at the convention at $3.00 each. Mail orders will be accepted by the American Society for Quality Control, Inc., 70 East 45th Street, New York, N. Y., at $3.50 each.

TECHNICAL PROGRAM—The most diversified yet offered. Speakers of world renown will describe the techniques they have used to make successful installations or solve their statistical quality problems. See the following pages for detailed program.

7TH ANNUAL ASQC CONVENTION TECHNICAL SESSIONS

SERIES	A	B	C	D
PERIOD				
1	Theme: **General Interest.** A. OLADKO, Plant Mgr., Johnson & Johnson, New Brunswick, N. J. Panel: DR. A. V. FEIGENBAUM, Manager of Programming, Aircraft Nuclear Propulsion Project, G. E. Company, Cincinnati 15, Ohio. H. E. THOMPSON, Director of Research, Anaconda Wire & Cable Co., Hastings on Hudson 6, N. Y. W. H. SMITH, Manager, Analysis Dept., Q. C. Office, Ford Motor Co., Dearborn, Mich. Subject: WHAT IS THE QUALITY CONTROL JOB?	Theme: **Armed Services—Ordnance.** Speaker: ARTHUR STEIN, Ord. Eng., Chief, Quality Control Engineering Section, Ordnance Ammunition Center, Joliet, Ill. Subject: QUALITY CONTROL PROJECT FOR 105MM AMMUNITION. Speaker: M. L. FRIEDHTENICHT, Manager, Ordnance Gauge Lab., Frankford Arsenal, Phila., Pa. Subject: U. S. ARMY ORDNANCE GAUGING PROBLEMS AND PRACTICES.	Theme: **Chemical Industry—General.** Speaker: R. M. HOFSTEAD, Spec. Asst. to Prod. Mgr. and H. W. ISLEIB, Head, Chem. Extract Dept., Bristol Laboratories, Inc., Syracuse, N. Y. Subject: STATISTICAL CONTROL IN CONTINUOUS CHEMICAL PROCESSING. Speaker: J. A. MITCHELL, Chief Chemical Engineer, Tennessee Eastman Corp., Kingsport, Tenn. Subject: PLANT SCALE EXPERIMENTS IN CHEMICAL PRODUCTION.	Theme: **Metals Inspection.** Speaker: H. J. BECKER, American Steel & Wire Co., Waukegan 1, Ill. Subject: ERRORS OF MEASUREMENT. Speaker: A. H. MAACK, Q. C. Engineer, International Harvester Co., Wisconsin Steel Works, Chicago 17, Ill. Subject: STATISTICAL METHODS FOR PRODUCT WEIGHT CONTROL.
2	Theme: **General Interest.** Speaker: WM. COMBERG, Director of the Management Engineering Dept., International Ladies Garment Workers Union, New York 19, N. Y. Subject: THE UNION LOOKS AT QUALITY CONTROL. Speaker: CARL E. HOOVER, Quality Control Administrator, Perfect Circle Corp., Hagerstown, Indiana. Subject: THE HUMAN RELATIONS ASPECT OF QUALITY CONTROL.	Theme: **Armed Services—Sampling Inspection.** Subject: H. M. ROSENBLATT, Head, Statistics Branch, Q. C. Division, Dept. of the Navy, Bureau of Ordnance, Washington 25, D. C. Subject: ORDNANCE STANDARD 80 — ACCEPTANCE INSPECTION BY VARIABLES. Speaker: H. WEINGARTEN, Statistics Branch, Q. C. Division, Dept. of the Navy, Bureau of Ordnance, Washington 25, D. C. Subject: ORDNANCE STANDARD 81 — ACCEPTANCE INSPECTION ON A MOVING LINE.	Theme: **Chemical Industry—Pharmaceutical Applications.** Speaker: T. J. MORAN, S. Q. C. Supervisor, Wyeth, Inc., West Chester, Pa. Subject: APPLICATIONS OF STATISTICAL QUALITY CONTROL IN THE PHARMACEUTICAL INDUSTRY. Speaker: C. I. BLISS, Biometrician, The Connecticut Agricultural Experiment Station, New Haven 4, Conn. Subject: ROLE OF A BIOMETRICIAN IN THE PHARMACEUTICAL INDUSTRY — ILLUSTRATED.	Theme: **Automotive Industry.** Speaker: PAUL ROCHE, Chief, Q. C., Detroit Arsenal, Centerline, Mich. Subject: MILITARY INSPECTION PROCEDURES OF VEHICLES & PARTS. Speaker: ALLEN EVANS, Q. C., Foundry Div., International Harvester Co., Indianapolis, Ind. Subject: Q. C. IN AN AUTOMOTIVE FOUNDRY.
3	Theme: **Quality Control Education and Training.** Speaker: DR. A. V. FEIGENBAUM, Manager of Programming, Aircraft Nuclear Propulsion Project, G. E. Company, Cincinnati 15, Ohio. Subject: COMPANY EDUCATION ON THE QUALITY PROBLEM. Speaker: RALPH WAREHAM, President, Ralph Wareham & Assoc., Chappaqua, N. Y. Subject: METHODS OF TRAINING FOR Q. C. ENGINEERS & SUPERVISORS.	Theme: **Armed Services—Aircraft.** Speaker: PHIL I. HARR, Quality Mgr., Fairchild Aircraft, Hagerstown, Md. Subject: QUALITY CONTROL IN THE AIRCRAFT INDUSTRY. Film. Subject: PRACTICAL APPLICATION OF STATISTICAL QUALITY CONTROLS IN THE AIRCRAFT INDUSTRY.	Theme: **Chemical Industry — Petroleum Applications.** Speaker: JAMES H. MATHENY, The Texas Company, New York 17, N. Y. Subject: THE APPLICATION OF STATISTICAL METHODS IN RESEARCH AND DEVELOPMENT. Speaker: C. T. SHEWELL, Research Specialist, Humble Oil & Refining Co., Technical and Research Division, Baytown, Texas. Subject: SOME APPLICATIONS OF STATISTICS IN A REFINERY.	Theme: **Computer Applications in the Metals Industry.** Speaker: D. H. W. ALLAN, Asst. Metallurgist, Processing Div., Metallurgical Dept., The Steel Co. of Canada, Ltd., Hamilton, Canada. Subject: APPLICATION OF I. B. M. EQUIPMENT TO A METALLURGICAL CORRELATION PROBLEM. Speaker: D. S. LECKIE, Q. C. Eng., Republic Steel Corp., Cleveland 1, Ohio and R. F. CAIN, Asst. Supt., Quality Control, Republic Steel Corp., Canton, O. Subject: APPLICATION OF CONSOLIDATED COMPUTER TO THE SOLUTION OF A METALLURGICAL CORRELATION PROBLEM.
4	Theme: **Engineering and Quality Control.** Speaker: PROF. E. BUCKINGHAM, Mass. Inst. of Technology, Cambridge 39, Mass. Subject: ANALYSIS OF DIMENSIONS AND TOLERANCES. Speaker: DR. J. H. DAVIDSON, Head of Statistical Methods Section, Electro-Mechanical Division, General Engineering Lab., G. E. Co., Schenectady 5, N. Y. Subject: STATISTICAL METHODS AND THE ENGINEER.	Theme: **Armed Services—MIL-Q-5923A.** Speakers for Military: 1. J. G. SCHNEIDER, Colonel, U.S.A.F., Acting Chief, Quality Control Div., Headquarters, Air Materiel Command, Wright-Patterson Air Force Base, Dayton, Ohio. 2. O. C. GRIFFITH, Lt. Colonel, U.S.A.F., Chief Operations Office, Quality Control, Headquarters, Air Materiel Command, Wright-Patterson Air Force Base Dayton, Ohio. Speakers for Industry: 1. JOSEPH PALL, Quality Control Manager, Glenn L. Martin Company, Baltimore 3, Md. 2. H. SIMPSON, General Electric Company, A.G.T. Division, Cincinnati, Ohio.	Theme: **Textile Industry.** Speaker: E. S. RUDNICK, Dir. of Research, Wamsutta Mills, New Bedford, Mass. Subject: CONTROL CHARTS & QUALITY LEVEL APPLICATIONS IN TEXTILES. Moderator: DR. D. S. HAMBY, School of Textiles, North Carolina State, Raleigh, N. C. Panel: F. J. O'NEIL, Dir. Phys. Res. Dept., Pacific Mills, Lawrence, Mass. S. E. PATRICK, JR., R. & D. Dept., Saco-Lowell Shops, Biddeford, Me. DR. L. H. HANCE, Inst. of Textile Tech., Charlottesville, Va. J. W. STUART, Dir. of Sales, Uster Corp., Charlotte, N. C. Discussion: EVENNESS TESTING APPLIED TO TEXTILE QUALITY CONTROL.	Theme: **Metals Industry.** Speaker: F. G. SMITH, Metallurgist, The American Brass Co., Waterbury 20, Conn. Subject: STATISTICAL QUALITY CONTROL IN THE AMERICAN BRASS CO. Speaker: F. G. NORRIS, Metallurgical Eng., Wheeling Steel Corp., Steubenville, O. Subject: TESTING PRODUCTION DATA FOR NORMALITY.
5	Theme: **General Interest.** Speaker: H. T. HALLOWELL, JR., President, Standard Pressed Steel Co., Jenkintown, Pa. Subject: INSTALLING A QUALITY CONTROL PROGRAM. Speaker: C. R. SCOTT, JR., Manager, Otis Elevator Co., Yonkers 1, N. Y. Subject: MANAGEMENT'S USE OF QUALITY CONTROL.	Theme: **Armed Services—MIL Standards.** Speaker: R. A. MOODY, Director, Office of Standardization, Defense Supply Management Agency, Washington 25, D. C. Subject: SPECIFICATIONS AND STANDARDS AS TOOLS OF MILITARY STANDARDIZATION — THEIR DEVELOPMENT AND THEIR CO-ORDINATION WITH INDUSTRY. Panel: To be announced. Subject: Panel discussion.	Theme: **Textile Industry.** Speaker: A. G. KLOCK, Q. C. Supt., Bigelow-Sanford Carpet Co., Thompsonville, Conn. Subject: INSPECTION OF VISUAL CHARACTERISTICS IN TEXTILES. Speaker: DR. J. LABARTHE, JR., Senior Fellow, Mellon Institute of Industrial Research, University of Pittsburgh, Pittsburgh 13, Pa. Subject: THE CONSUMER'S STAKE IN TEXTILE QUALITY—OR—"WHAT IS THE USE" IN TESTING.	Theme: **Plant Tour.** QM General Testing Laboratories and Plant Tour of Quartermaster Depot and Manufacturing Division, Philadelphia, Pa.

SERIES	E	F	G	H
PERIOD	Theme: **Reliability of Electronic Equipment.**	Theme: **Application in the Process Industries.**	Theme: **Plastics Manufacturing.**	Theme: **Advanced Educational Sessions.**
1	Speaker: C. R. HERD, Supervisor of Statistics Dept., Aeronautical Radio Inc., Washington 5, D. C. Subject: APPLICATIONS OF STATISTICAL METHODS IN EVALUATING PERFORMANCE OF ELECTRONIC EQUIPMENT. Speaker: R. D. GUILD, Sylvania Electric Products Inc., Emporium, Pa. Subject: STATISTICAL APPRAISAL OF VACUUM TUBE QUALITY.	Speaker: P. E. CNAEDINGER, Director of Quality Control, Dominion Rubber Co. Ltd., Montreal 24, P. Q., Canada. Subject: ATTAINING UNIFORMITY IN PROCESSING RUBBER BATCHES. Speaker: B. E. SOOY, Chief of Quality Control, Gardner Board & Carton Co., Middletown, Ohio. Subject: SOME APPLICATIONS OF STATISTICAL QUALITY CONTROL IN THE PAPER BOX BOARD AND PRINTING INDUSTRIES.	Speaker: R. C. BOYD, Heat Thermoplastics Works Laboratory, Bakelite Company Division, Union Carbide & Carbon Corp., Bound Brook, N. J. Subject: PROCESS CONTROL IN A PLASTICS MANUFACTURING PLANT. Speaker: C. H. ADAMS, Plastics Division, Monsanto Chemical Co., Springfield, Mass. Subject: STATISTICS APPLIED TO PLASTICS EVALUATION.	Speaker: E. C. HARRINGTON, JR., Mgr. of Industrial Statistics, Monsanto Chemical Company, Springfield 2, Mass. Subject: GENERAL INTRODUCTION AND SAMPLING. VARIATION, VARIANCE & VARIANCE RATIO TEST.
2	Theme: **Life Testing Electrical and Electronic Equipment.** Speaker: PROF. BENJ. EPSTEIN, Dept. of Mathematics, Wayne University, Detroit 1, Mich. Subject: A STATISTICAL THEORY OF LIFE TESTING AND SOME OF ITS APPLICATIONS. Speaker: J. A. DAVIES, Supv. of Statistical Control Methods, General Electric Co., Owensboro, Ky. Subject: HOW RELIABLE IS YOUR LIFE TESTING PROCEDURE?	Theme: **Mathematical Statistics.** Speaker: PROF. A. W. TUCKER, Math. Dept., Fine Hall, Princeton University, Princeton, N. J. Subject: LINEAR PROGRAMMING. Speaker: DR. LEE CRUMP, Head Statistics Section, Atomic Energy Project, University of Rochester, Rochester 20, N. Y. Subject: EXPERIMENTAL DESIGN.	Theme: **Quality Control Applications in the Food Industry.** Speakers: D. A. BRANDT and E. S. EDELMAN, Schenley Distillers, Cincinnati 2, Ohio. Subject: THE EFFECT OF THE CONCENTRATION AND FLAVOR INTENSITY IN A FOOD PRODUCT ON THE ORGANOLEPTIC SENSES. Speaker: R. I. TENNEY, President, Wahl-Henius Institute, Chicago, Ill. Subject: PROCESS CONTROL IN THE BREWING INDUSTRY BY STATISTICAL METHODS	Theme: **Advanced Educational Sessions.** Speaker: NORMAN GARNER, Analyt. Stat., Qual. Assurance Off., Phila. Quartermaster Depot, U. S. Army, Phila. 45, Pa. Subject: SAMPLING VARIATION OF AVERAGES—STUDENT'S "t" TEST. SAMPLE SIZE—POWER OF A TEST.
3	Theme: **Gauging and Gauge Design.** Speaker: C. H. BORNEMAN, Manufacturing Engineering Services Dept., G. E. Company, Schenectady 5, N. Y. Subject: THE DEVELOPMENT AND FUNCTIONS OF A GAUGE LABORATORY. Speaker: JOHN HARRINGTON, The DoAll Company, Des Plaines, Ill. Subject: THE IMPACT OF QUALITY CONTROL ON GAUGE DESIGN.	Theme: **Vendor Relations.** Speaker: J. P. WORTH, Chief Inspector, Electrolux Corp., Old Greenwich, Conn. Subject: WHO CONTROLS THE VENDOR'S QUALITY? Speaker: C. R. BURDICK, Supervisor of Statistical Analysis Section, Ford Motor Company, Dearborn, Mich. Subject: VENDOR RESPONSE TO THE QUALITY CONTROL APPROACH.	Theme: **Influences on Product Quality.** Speaker: E. A. LINDSAY, Electrical Engineer, Lamp Div., G. E. Co., Nela Park, Cleveland 12, Ohio. Subject: SPECIALIZED LIGHTING FOR INSPECTION AND CONTROL. R. F. BISBEE, Mgr. Quality Control, Westinghouse Electric Corp., Mansfield, Ohio. Speaker: Subject: PRETESTING PACKAGE PRODUCTS A VITAL PHASE OF Q. C.	Theme: **Advanced Educational Sessions.** Speakers: DR. M. A. BRUMBAUGH, Director of Statistics, Bristol Laboratories, Inc., Syracuse, N. Y. and D. B. DE LURY, Director, Dept. of Mathematical Statist., Ontario Research Foundation, Toronto, Canada. Subject: (a) DESIGN OF EXPER.-INTROD.-RANDOMIZED BLOCKS, LATIN SQS., ETC. (b) DESIGN OF EXPER.-) FACTOR & 2 FACTOR. DESIGN-ANALYSIS OF VARIANCE
4	Theme: **Quality Control in Precision Manufacturing.** Speaker: E. R. CLOSE, Chief Inspector, Instrument Div., Bausch & Lomb Optical Co., Rochester 2, N. Y. Subject: A PRACTICAL APPROACH TO LOSS REDUCTION IN PRECISION MFG. Speaker: A. S. HAYES, Q. C. Supervisor, Perfect Circle Co., Hagerstown, Ind. Subject: CONTROLLING VISUAL CHARACTERISTICS ON PRECISION PARTS.	Theme: **Operations Research.** Speaker: J. B. LATHROP, Arthur D. Little, Inc., Cambridge 42, Mass. Subject: INDUSTRIAL APPLICATIONS OF OPERATIONS RESEARCH. Panel Leader: DR. OLMSTEAD. Panel: DR. S. S. WILKS, Princeton University. W. R. WEAVER, Republic Steel Corp. J. B. LATHROP, Arthur D. Little, Inc. DR. HUGH SMALLWOOD, U. S. Rubber Co. Subject: THE PLACE OF OPERATIONS RESEARCH VS. QUALITY CONTROL.	Theme: **Industrial Engineering.** Speaker: A. E. LONGLEY, Mgr. of Training, Atlas Steels Ltd., Welland, Ontario, Canada. Subject: INDUSTRIAL ENGINEERING AND QUALITY CONTROL. Speaker: C. L. BRISLEY, Ind. Engineering Mgr., Wolverine Tube Division, Calumet & Hecla Consolidated Copper Co., Detroit 9, Mich. Subject: WORK SAMPLING.	Theme: **Advanced Educational Sessions.** Speakers: DR. M. A. BRUMBAUGH, Director of Statistics, Bristol Laboratories, Inc., Syracuse, N. Y. and D. B. DE LURY, Director, Dept. of Mathematical Statistics, Ontario Research Foundation, Toronto, Canada. Subject: (a) DESIGN OF EXPERIMENTS—3 and 4 FACTORS. (b) DESIGN OF EXPERIMENTS—CONFOUNDING AND FRACTIONAL REPLICATION.
5	Theme: **Plant Tour.** FORD MOTOR COMPANY, Chester, Pa.	Theme: **Mathematical Statistics.** Speaker: DR. W. E. DEMING, Prof. of Statistics, New York University and Specialist in Sampling Procedures, Bureau of the Budget. Subject: THE THEORY OF SAMPLING. Speaker: PROF. A. J. DUNCAN, Associate Professor of Statistics, Johns Hopkins University, 34th and Charles Streets, Baltimore 18, Md. Subject: CHI SQUARE TESTS OF INDEPENDENCE.	Theme: **Plant Tour.** THE BUDD COMPANY, Philadelphia, Pa.	Theme: **Advanced Educational Sessions.** Speakers: MISS B. B. DAY, Principal Statistician, U. S. Naval Engineering Experimental Station, Annapolis, Md. F. R. DEL PRIORE and E. SAX, Statisticians, U. S. Naval Eng. Experimental Sta., Annapolis, Md. Subject: (a) CORRELATION & REGRESSION — LINEAR. (b) CORRELATION & REGRESSION — MULTIPLE & CURVILINEAR.

Directory of Convention Exhibitors*

Booths 1-2
Information about ASQC, membership applications, pins

Booths 3-4
General Electric Co., Schenectady, N.Y.
Electrical appliances, quality control indicator

Booth 5
Greenfield Tap and Die Co., Greenfield, Mass.
Thread and plug gages

Booth 6
A. G. Davis Gage & Engineering Co.
Gages

Booth 7
ASQC Proceedings

Booth 8
Ralph E. Burt Associates, 20 Worthington St., Springfield, Mass.
Creators of quality mindedness campaigns

Booths 9-10
Marchant Calculators Inc., 1475 Powell St., Oakland, Cal.
High speed calculators

Booths 11-12
Met-L-Check Co. Hawthorne, Cal.
Lectro-Etch Co., Cleveland, Ohio
New Hermes Engraving Machine Corp., New York, N. Y.
Marking and Inspection Equipment

Booth 13
Elliott Service Co., 30 N. MacQuesten Pkwy., Mt. Vernon, N.Y.
Quality mindedness through use of illustrated posters

Booths 14-15
Federal Products Corp., 1144 Eddy St., Providence, R. I.
Gages and instruments, dial gages, comparators

Booths 16-17
Optical Gaging Products Inc., 14 [illegible] bes St., Rochester, N.Y.
Optical comparators

Booths 18-19
Frank T. Griswold Co., Wayne, Pa.
Optical gaging equipment

Booth 20
The Van Keuren Company, 176 Waltham St., Watertown, Mass.
Optical flats

Booths 21-22
American Cystoscope Co., 1241 Lafayette Ave., New York, N.Y.
Internal measurement

Booth 23
Cleveland Instrument Co., 735 Carnegie Ave., Cleveland, Ohio
Electronic gaging equipment

Booths 24, 25 & 26
Moore Products, H. & Lycoming Sts., Philadelphia, Pa.
Air gaging equipment

Booth 27
Lawley Granite Surface Plate Co. surface plates

Booth 28
Taft-Peirce Mfg. Co., 32 Mechanic Ave., Woonsocket, R.I.
Thread gages, ring and plug

Booth 29
Cosa Corporation, Chrysler Bldg., 405 Lexington Ave., New York, N.Y. Multi-dimension high speed inspection machines

Booths 30-31
Sheffield Corporation, Dayton, Ohio
Gages, comparators

Booths 32-33
DoAll Company, 254 N. Laurel Ave., Des Plaines, Ill.
Gage blocks, comparators, micrometers

Booths 34, 35 & 36
Johnson Gage Co., 534 Cottage Grove Road, Bloomfield, Conn.
Dial thread gages

Booth 37
American Instrument Co., Silver Spring, Md.
Magne Gauge for checking plating thickness, recording type materials strength gages

Booth 38
Micrometrical Mfg. Co., 345 S. Main St., Ann Arbor, Mich.
Profilometer for checking surface smoothness

Booth 39
N. A. Woodworth, 1300 E. Nine Mile Road, Ferndale, Mich.
Thread gages

Booth 40
Brush Development Co., 3405 Perkins Ave., Cleveland, Ohio
Optical equipment for surface analyses of metals

Booth 41
John Chatillon & Sons, New York, N.Y.
Precision springs and scales

Booth 42
L. S. Starrett, Athol, Mass.
Micrometers, gaging equipment, Comparators

Booth 43
Jones & Lamson Machine Co., Springfield, Vt.
Optical comparators, machine tools

Booth 44
Friden Calculator Co., San Leandro, Cal.
High speed electric calculating machines

Booth 45
Collins Micro-Flat Co., 2326 E. 8th St., Los Angeles, Cal.
Surface plates

Booths 46-47
Bryant Chucking Grinder Co., Clinton St., Springfield, Vt.
Internal thread gages

Booth 48
Tinius Olsen Instrument Co., Penn St. and Pulaski Ave., Philadelphia, Pa.
Tensile testers, optical and recording-type pyrometers for high temperature gaging

Booths 49-50
Pratt-Whitney Div., Niles-Bement-Pond, 1 Charter Oak Road, West Hartford, Conn.
Gage blocks, ring and thread gages

Booths 51-52
Monroe Calculating Machine Co., Inc., 555 Mitchell St., Orange, N.J.
High speed electronic calculators

Booths 53-54
Nilsson Gage Co., Poughkeepsie, N.Y.
Bore gages, ring gages

Booths 55-56
Bausch and Lomb Optical Co., 635 St. Paul St., Rochester N.Y.
Optical gaging equipment, comparators, microscopes

Booth 61
Scale Specialties & Systems Co., Roseland, N.J.
Weight calculators

Booth 62
Size Control Co., 2500 W. Washington Blvd., Chicago, Ill.
Control charting procedures

Booths 63-64
Tubular Micrometer Co., St. James, Minn.
Micrometers

Booths 65-66
Webber Gage Co., 12900 Triskett Road, Cleveland, Ohio
Precision gage blocks

Booth 67
Service Diamond Tool Co., 2505 Burdette Ave., Ferndale, Mich.
Hardness testing equipment

Booths 68-69
Coca Cola Company, New York, N.Y.
Courtesy booths

Booths 70, 71 & 72
ASQC Book Booths
Latest in quality control literature

*Listing as of April 8, 1953

Ladies' Program

Wednesday, May 27, 1953

8:30 to 10:30 a.m.
Coffee, tea, cookies—Lafayette Room, Benjamin Franklin Hotel

1:00 to 6:00 p.m.
Valley Forge guided historical tour—starts at Benjamin Franklin Hotel

Thursday, May 28, 1953

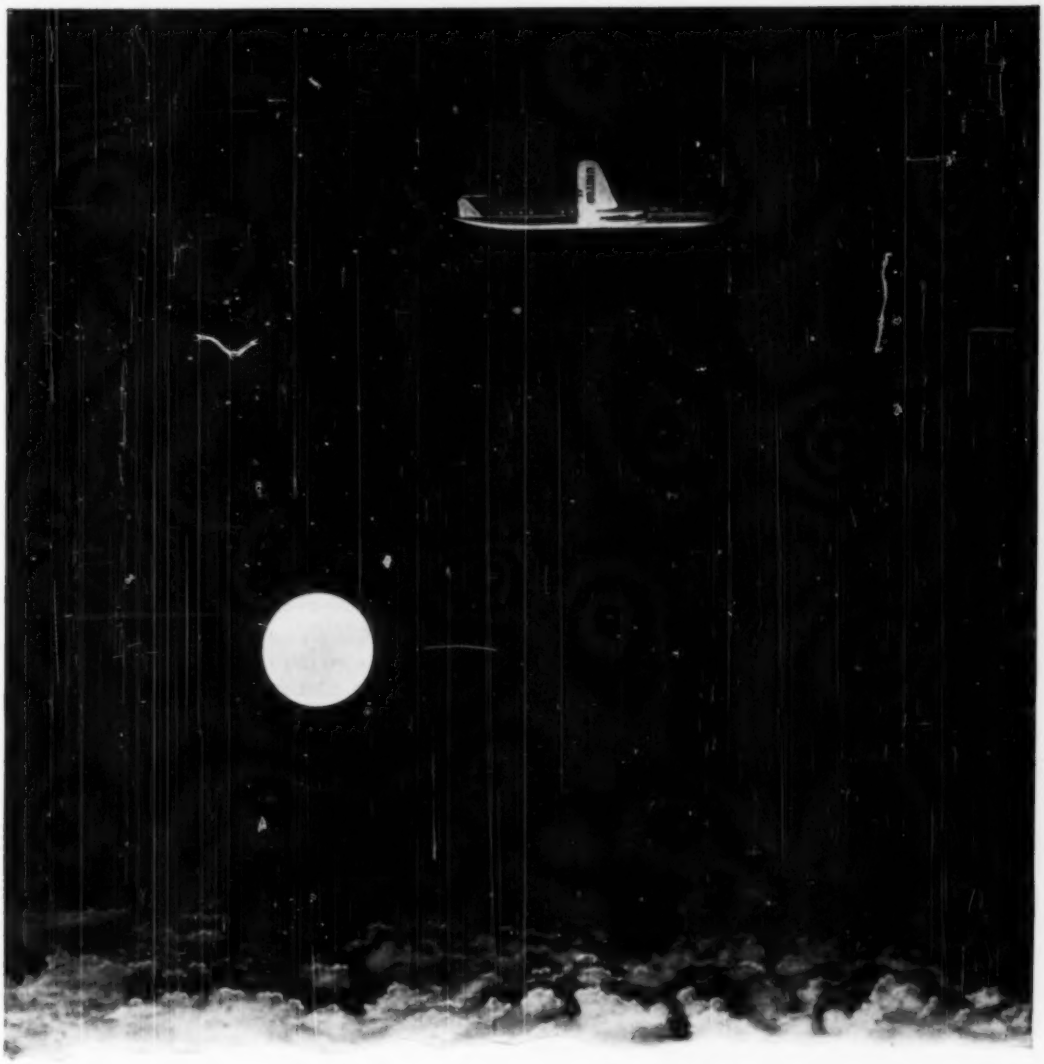
8:30 to 10:30 a.m.
Coffee, tea, cookies—Lafayette Room, Benjamin Franklin Hotel

1:00 p.m.
Luncheon and Fashion Show—by Joanne Trulick Shop

Friday, May 29, 1953

8:30 to 10:30 a.m.
Coffee, tea, cookies—Lafayette Room, Benjamin Franklin Hotel

Thereafter
Shopping tours and a walking tour of historical Philadelphia



Reaching for a star

Nowadays the lights of giant Mainliners seem to move among the stars as familiar neighbors, spanning the nation's skies with year-around regularity.

Our aim is to improve performance still more, until all schedules are 100% on-time. An impossibility, you'd say? Perhaps so, for no form of transportation—ground, sea or air—has ever achieved it. But "a man's reach should exceed his grasp," and it's the very fact of 12,800 people reaching farther into the future that brings you more dependable service today.

The finest modern airliners . . . the only airline maintenance base of its kind in the world . . . around-and-over-the-weather flying techniques . . . the latest electronic landing aids . . . all these have helped us advance to today's high standards. But most important of all are people—men and women who think deeper and work harder toward making United Air Lines Mainliners as dependable as the stars in their courses. For reservations, call or write United or an Authorized Travel Agent.

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SEE YOU at the SEVENTH ASQC CONVENTION*

And while you're there, be sure to visit BOOTH 13 for your free kit of ELLIOTT'S Quality-Cost posters and news pictures.

You're in for a pleasant surprise when you learn how inexpensive these colorful weekly displays really are! Mounted in either steel or chrome-finish display panels, ELLIOTT Q-C posters will "sell" your entire work force on the importance of quality workmanship at minimum manufacturing costs!

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Hydraulic Magic

in the New Ford Tractor *Golden Jubilee* MODEL

The trend toward boosting the efficiency of power farming and reducing human effort with hydraulics began nearly one million Ford-built Tractors ago. Now, it gains great new impetus. The new Ford Tractor's Live-Action Hydraulic System offers many new operating advantages and unfolds a great new range of usefulness never before achieved.

Gone is the wait for a pressure build up—the time lag between moving the control lever and getting hydraulic action. Almost magically the new Ford Tractor's Live-Action Hydraulic System responds instantly at any engine speed.

The engine-driven hydraulic pump delivers a volume of oil continuously. Whenever the engine is running, the hydraulic power is "there" for immediate use. Gear shifting and clutch pedaling are reduced to a minimum. Attaching implements is easier than ever.

More new magic in this system is the way Hy-Trol gives a choice of hydraulic speeds to fit the job, plus new efficiency of hydraulically operated remote-control equipment. In addition, Selec-Trol* permits operating either front or rear mounted equipment from the new Ford Tractor's Live-Action Hydraulic System.

Ford Tractor *Hydraulic Touch Control, Constant Draft Control, Implement Position Control*—all of these time-proved advantages are quickened in response, to make good farming more nearly automatic and less tiring. This hydraulic system's speed of response and the fast-acting governor of the new Ford "Red Tiger" engine team up to deliver newer, smoother, more efficient power to farming operations.

If you are interested in learning more about this great new Ford Tractor, write us for your copy of the 24-page Ford Tractor Catalog. It gives many more details about "Hydraulic Magic" as well as about dozens of other outstanding features.

DEARBORN MOTORS CORPORATION • Birmingham, Michigan
National Marketing Organization for the Ford Tractor and Dearborn Farm Equipment

Ford TRACTOR

Ford Farming
MEANS LESS WORK...MORE INCOME PER ACRE

*Sold separately

Special Applications for Quality Control Charts*

WYATT H. LEWIS

General Electric Company

Over the past several years literally hundreds of quality control operators have attested to the fact that the Shewhart quality control chart does work. Speeches, papers, magazine articles, and books have been used to reveal this remarkable device to American Industry.

It has been proven that the control chart obeys the laws of mathematical probability and will detect the presence of assignable causes operating on the process. It will also tell when these assignable causes are operating so the quality control investigator can sally forth at the right time in an endeavor to identify the cause or causes and answer the other questions of who, what, where, and why. The latter job is detective work that the control chart will not do by itself. This is up to the quality control engineer or persons assisting him.

Let us say then without further argument that the control chart does quite well the job expected of it—namely, telling when assignable causes of variation are operating. Not many quality control men would want to debate that statement. There is, however, a large field open for debate on the manner in which quality control charts are applied. Aside from such matters as frequency of sample, size of sample, nature of subgrouping, etc., there are the following questions that might evoke a lively discussion among quality control personnel.

1. Are control charts for averages too confusing for use of shop operators? (They are accustomed to thinking in terms of measurement and specification for individual items.)
2. Should control charts be reserved for use in the engineering laboratory?
3. How many quality characteristics on how many items should be charted?
4. To what extent should control charts be routinized?
5. What use can be made of the quality control chart in special investigations of short duration?

*Paper presented on the program of the Sixth Annual Convention of ASQC in Syracuse, New York. May, 1952.

These are just a few of the questions that can arise in trying to apply control charts. Furthermore, they are questions that have to be answered to permit successful day-by-day operation of a quality control program.

I'll tell you how we do it, but first let me acquaint you with our type of operation. The Ontario (California) plant of the General Electric Company manufactures automatic flatirons and steam irons. It is almost completely integrated. The calrod heating element is manufactured at Ontario and cast into a soleplate —either aluminum or cast iron. The soleplates leave the foundry and go through an automatic machining line. After machining, the soleplates are polished and buffed. In the case of cast iron, a protective and decorative plate of nickel and chromium is used. We also mold handles for the irons in the plastics section. Tops are blanked and drawn in the press section. These are finished and plated, ready for assembly. The press section also stamps out small parts used in the fabrication of the thermostat and tank for the steam iron. Heater cord is purchased in reels, cut to length and prepared for assembly with plug and connections. All these various components are brought together on an assembly conveyor. The completed irons are then run over an energized conveyor where they are heated and tested. The irons are then buffed, given a final visual inspection and packed for shipment.

Perhaps the first thing you would notice upon taking a quality control tour through our factory would be the lack of X, R charts at the location of the operation. There are several reasons for this. First we have no screw machine section; all screw machine parts are purchased. In the second place our machining operations are highly standardized, in-line operations. Through years of experience, cutter life has been determined and cutters are changed after so many thousand pieces run. Initial check on set-up has been found adequate; hence, control charts in this section would not pay their way.

We do have several X, R charts in the factory such as calrod winding resistance, calrod tubing diameter, straightness and length. Calrod wattage is also plotted on a control sample although all units are 100 percent inspected automatically on a test machine. A few special machining operations also use conventional X, R charts, such as the location of the filler tube hole in the steam tank riser tube.

The thermostat assembly section has proved to be the best area for applying X, R charts for routine control purposes. Commonplace applications include strengths of welds for contacts to contact springs, bimetal assembly welds, etc.

One of the most valuable routine applications has been on thermostat contact pressure and thermostat rocker arm pressure. Both of these quality characteristics are influenced by the form of the contact spring and adjusting spring. Due to changes in form for various lots upon heat treating, a gaging and hand forming operation has been found necessary. The foreman of the thermostat section governs the setting of the gage for spring forming by the X, R charts on contact and rocker arm pressures.

It is interesting to note that we started this job with a regular Shewhart control chart several years ago. Perhaps we have had exceptional foremen in this position, but we have experienced very little difficulty in getting the idea of control limits established as compared to specification limits. Perhaps one device that has helped in this regard is the use of the out-of-bounds area (crosshatched) that is figured in from the specification limits. (See Fig. 1). This device and its calculation have been covered in the literature.[1, 2] You will note that in addition to these so-called modified limits we have used conventional 3-σ statistical limits to define the normal operation. This has the beneficial

(1) "Dimensional Quality Control Primer," Federal Products Corp. 1946

(2) Edward M. Schrock, "Quality Control and Statistical Methods," Reinhold Publishing Co., New York, 1950, pp. 128-137.

HUNTER
SPRING COMPANY
LANSDALE, PENNSYLVANIA

May 7, 1953

Dear Bill:

As an early advocate of Industrial Quality Control and as a pioneer of the concept of Quality Reporting, Hunter Spring Company has witnessed, with great satisfaction, the amazingly rapid growth of the American Society For Quality Control and the generally increasing acceptance and use of Quality Control methods by industry.

It is our firm belief that, in the near future, all industry will require that "quality" be translated in terms of a product's conformance to desired characteristics—that the quality of a product be measured, using modern inspection methods and apparatus; controlled by using modern methods of Quality Control; and recorded and reported in the form of a manufacturer's Quality Report.

We also believe that both manufacturer and consumer will greatly benefit thereby.

That's why we, at Hunter Spring Company, have devoted much time and energy to the development of our own Quality Control program, have encouraged active participation by our members in the American Society For Quality Control, and have—by means of advertising, editorial articles in the trade press, and the sponsorship of our own Quality Control Courses—attempted to disseminate what information we have obtained to others.

Sincerely,

Fred

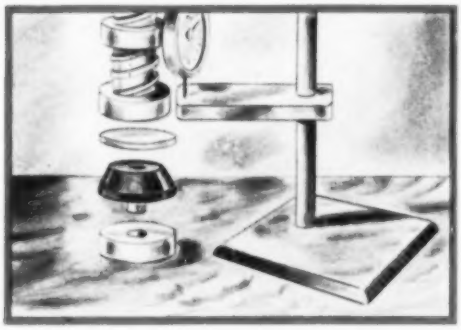
HUNTER SPRING COMPANY
F. C. Schulze, Chf. Insp.

FCS:gst

Less BOUNCE *to the Ounce!*

(Thanks to S.Q.C.)

Ability to absorb shock and vibration is a prime property of rubber. But resiliency of rubber must be held within close limits on a wide variety of rubber components. Examples are motor mounts for automobile engines, tank motors and electronic instruments. Excessive resiliency in motor mounts must be avoided. It is a problem of obtaining and maintaining optimum control of shock and vibration with *"less bounce to the ounce"* of rubber.



Example of a deflection test of a motor mount. Continuous tests are plotted on modified control charts. Corrective action is taken when processes drift away from specifications.

At The Ohio Rubber Company, factory control of deflection testing of load-bearing rubber components is under the supervision of Statistical Quality Control. Special types of deflection control testing equipment were perfected for the purpose.

Uniformity of testing procedures is assured on a round-the-clock schedule by modified control charts and a program that assures conformance of all test personnel to identical procedures. S.Q.C. is the F.B.I. of The Ohio Rubber Company. The end result is close adherence to customers' specifications.

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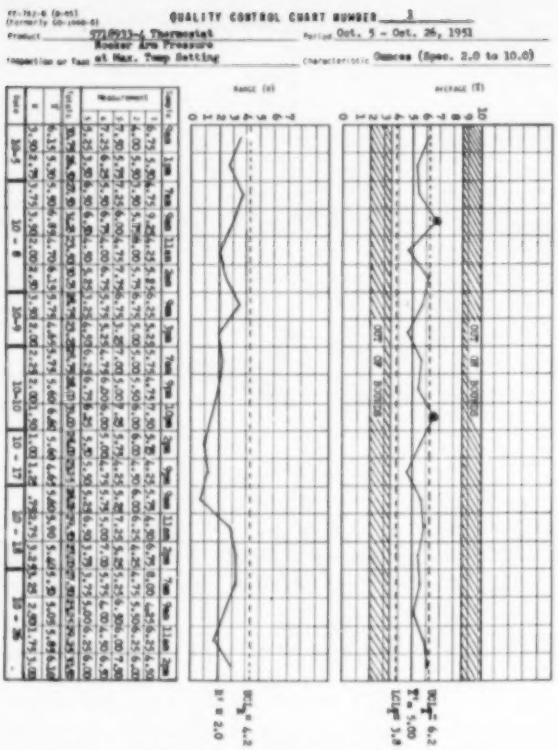

Figure 1—**Sample Control Chart on Thermostat Rocker Arm Pressure**

effect of keeping the process adjusted to the most desirable value. A point outside of statistical limits, but not yet out of bounds, would not be outside of specification. The product could be accepted for assembly into flat irons but action should be started toward readjusting spring form to bring pressures back to normal. The cross-hatched area, as appears in Figure 1, sets forth the concept that due to the variation of individual items the average must be carried at a safe distance inside the specification to keep from getting individual items outside specification limits. We have found this concept readily accepted by shop personnel.

In many cases, the quality control engineer is so imbued with a routine plan for controlling the over-all quality of a manufacturing operation that he is liable to make use of control charts only if they fit into this plan. If he does this he is not getting maximum use out of a very versatile tool. It is like using a hammer just for driving nails. A hammer can also be used for beating things back into shape.

Both the $\bar{X}$, R chart and the p chart can be used for special, short term investigations. Special data may be collected for such a chart when the data is not available from routine inspection records.

An example of what I am talking about is best illustrated by the following. Figure 2 shows a cast iron soleplate with the cast-in calrod heating element. Since this is a sand casting, it is necessary to thoroughly clean the sand off before the machining operations are performed in order to lengthen cutter life. To accomplish this the castings are tumbled in a special device filled with cascading shot. While the casting is being cleaned a small amount of the magnesium oxide insulating powder becomes loosened and falls out the ends of the calrod. This is an advantage since it leaves a slight recess to receive a sealing compound which seals the unit against penetration of oil and plating solutions. We started experiencing excessive losses of cast iron castings at the head of our assembly line where the sheath is trimmed off at the ends to expose the calrod terminals. The reason for this was that excess insulating powder was being removed in a percentage of soleplates. When these

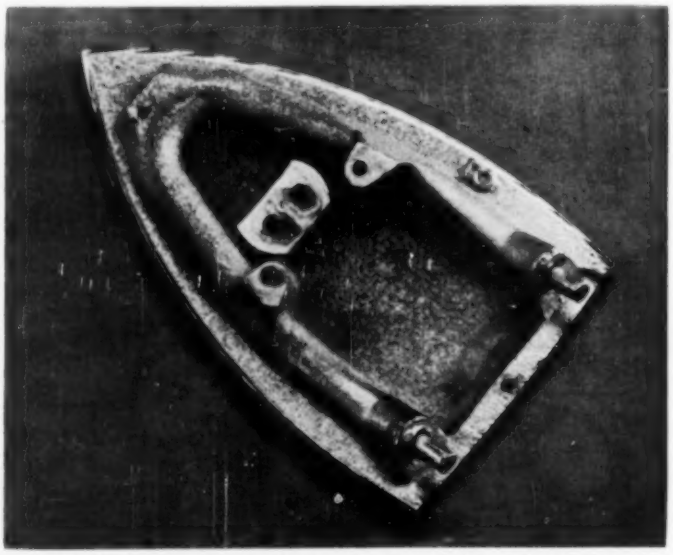

Figure 2—**Cast Iron Soleplate Showing the Cast-in Calrod Heating Element**

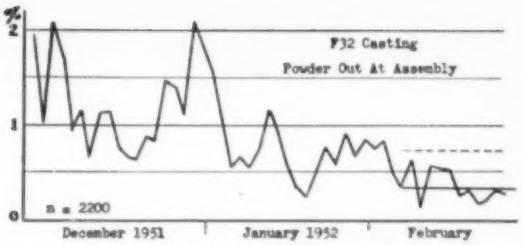

Figure 3—**P Chart of Soleplates Scrapped Because of Excess Powder Out**

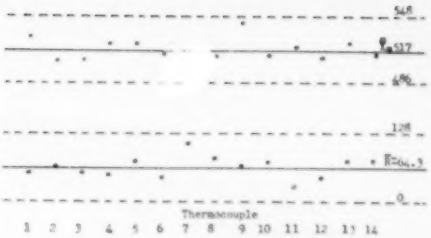

Figure 4—**Control Charts of Individual Thermocouple Readings**

were trimmed the sheath would collapse and the casting was lost. Since we had no inspection point at the head of the conveyor, we would learn of extensive losses after several hundred soleplates had been accumulated over a period of a week or two.

It was decided this loss could be prevented by the operator filling the ends of the calrod with sealing compound. When he came to a casting that looked as though it had excess powder knocked out of it, he would gage the surface of the powder with relation to the surface of the casting. This casting would then be set aside and filled with an electrical insulating cement which was allowed to set and dry out before sealing.

Although the weekly accumulations of scrapped soleplates at the sheath trimming operation dropped off somewhat, losses were still high. Preliminary investigation showed that the operator was not making full use of the gage on doubtful cases. After this was corrected, losses from accumulated scrap was still high. In order to tell what was going on we decided to get a daily count of castings lost at the sheath trimming operation. Since this was not a routine inspection point, an engineering assistant was asked to spend a few minutes at the end of the day to count the castings the operator had thrown out. The resulting data were kept on a p chart as shown in Fig. 3. It was evident that for a few days losses would be low and then they would rise, then they would drop again. A cycle seemed to be apparent. This pattern seemed to be established by the fact that lots of "powder out" castings that needed filling with insulation cement were accumulated, filled and sent through subsequent processes in a lot. This immediately indicated that something had gone sour with the salvaging operation. Investigation showed the cement was not setting properly. In fact it was nothing but powder. Further investigation showed that the operator was not properly mixing the binder in the cement. Another mystery solved by a relatively short range use of a p chart.

The X, R chart also lends itself to short range investigational work. Rather than use the somewhat involved mathematical process encountered in analysis of variance, an X, R chart will often do the job.

In making a certain temperature check, flatirons are tested on a device equipped with 14 thermocouples. We were suspicious that one of the 14 thermocouples might be giving us incorrect readings. One method would have been to run a test iron of known temperature over each of the thermocouples. This would have caused a shutdown of the device for a considerable duration and given us results under highly artificial circumstances; i.e., with extended time to establish equilibrium and with only one given iron at one given temperature.

Rather we recorded a series of flatiron temperatures for each thermocouple as appears in Table I. The readings for each thermocouple number were treated as a subgroup and given the X, R analysis to answer the question, "Is the variation from thermocouple to thermocouple greater than would be expected from the normal variation of flatiron temperatures presented at random to the thermocouples?" Thermocouple No. 9 which had more high readings than one might expect, was within the 3-σ control limit (See Fig. 4).

A second series of six readings for each thermocouple was taken (not shown). Again the average readings for thermocouple No. 9 was within 3-σ limits, actually plus 1.4 sigma from the mean of all thermocouples. This indicated a possible chance variation, but singled out thermocouple No. 9 for further check. All thermocouples were found to be satisfactory and attention was

TABLE I—**Temperature Reading, °F.**

THERMOCOUPLE NUMBER	DETERMINATION NO. 1	2	3	4	5	6	*Total*	*Avg.*	*Range*
1	525	530	530	550	550	495	3180	530	55
2	510	535	470	500	505	530	3050	508	65
3	530	540	500	500	495	485	3050	508	55
4	515	525	535	505	505	555	3140	523	50
5	520	560	515	510	550	485	3140	523	75
6	530	510	515	490	535	505	3085	514	45
7	440	550	480	520	495	500	2985	498	110
8	470	520	505	505	550	520	3070	512	80
9	530	550	580	555	515	530	3260	543	65
10	520	515	475	520	550	495	3075	513	75
11	510	505	515	535	530	525	3120	520	30
12	500	535	515	510	490	510	3060	510	45
13	530	525	495	565	490	540	3145	524	75
14	485	480	490	555	535	540	3085	514	75
						TOTALS	7240	900	

Underlined values not within specification.

$\bar{R} = 64.3 \quad n = 6$

$UCL_R = (2.004)(64.3) = 128$

$LCL_R = (0)(64.3) = 0$

$\bar{\bar{X}} = 517$

$UCL_{\bar{X}} = 517 + (.483)(64.3) = 548$

$LCL_{\bar{X}} = 517 - (.483)(64.3) = 486$

Figure 5—**Flatiron Handle**

then given to obtaining less variation in setting the calibration of the flatiron thermostats.

Figure 5 shows the picture of a handle for one of the flatirons. The open gap beneath the handle is bridged by a decorative metal nameplate that covers the top of the iron. Although the plastic handle is placed on a cooling fixture which spaces this gap, we had trouble holding the dimension die to the varying degrees of warpage of "pulling in" after removal from the cooling fixture. The tendency to "pull in" is a function of the "cure" on a handle. "Cure time," or the time the handle remains in the mold after being formed, has to be established for plastic compound of given flow rate (rate of plastic flow under heat and pressure). The flow rate varies from blend to blend of molding compound. If it varies too widely, the "soft" blends of compound result in inadequate cure and warpage results. (Other important factors governing cure time are mold temperature and temperature of preforms coming from the preheaters.)

In an endeavor to gain better control of the incoming molding compound, a sample of each blend of compound will be taken. Ten handles will be molded from each sample under essentially the same conditions; i.e., same press, same preheater, same operator, same cooling fixtures, and steam pressure closely controlled. The handles will be measured for length of gap. The measurements from handles from a given blend number will be treated as a subgroup and given the X, R test to see which blends depart from what we might normally expect. Out-of-control blends will either have to be returned to the vendor or we will have to set up special conditions to insure proper cure. Since we receive 10 to 20 blends in a shipment, it should not take long to obtain sufficient number of blends to permit the calculation of control limits.

We have had statistical quality control for almost ten years and we have been molding plastic handles for more than ten years, yet you see we are just now making a special application of the control chart to a problem that has just recently proven troublesome.

The control chart is a very useful tool and should be used not only for routine process control but for special applications such as those I have been discussing.

In conclusion we might review the questions raised at the beginning of this article and form some opinions. I think that the Shewhart control chart by itself may be difficult for shop personnel due to confusion between limits for averages and specification limits for individual items; however, much of this confusion can be overcome by use of an "out-of-bounds" zone on the chart as shown in Fig. 1. The control chart is also a very useful tool for the engineering laboratory and for relatively short range special investigational work. Its great value in this phase of quality control should not be overshadowed by its use in routine quality control plans.

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Note on the Use of Fixed Numbers of Defectives and Variable Sample Sizes in Sampling by Attributes.

C. C. CRAIG

University of Michigan

IT is a standard provision of single- and double-sampling plans that lots are to be rejected if the number of defectives found in the sample (or samples) is equal to or greater than a stated number. In practice a very common way of reducing the total inspection is to discontinue inspection as soon as the number of defectives on which the lot may be rejected is found.

To illustrate, suppose the double-sampling plan, $n_1 = 100$, $n_2 = 200$, $c_1 = 3$, $c_2 = 8$ is being used and that the inspector in the course of running through the first sample accumulates the 9th defective on the 82nd piece. The lot can be rejected and he does so without looking at any more pieces. Or it may be that on completing the first sample he has a total of 5 defectives and he starts the second sample. On the 75th piece of this he finds the 9th defective and he rejects the lot on a total inspection of 175 pieces.

It is a fair question to ask how the inspector can use information like this, the number of pieces looked at to find a given number of defectives, to make inferences concerning the lot quality or concerning the process from which the lot came. An answer commonly given is that the inspector should complete the first sample anyway and make inferences or keep a control chart on the basis of a constant sample size.

It may be of interest to point out how one can use attributes sampling data in which the records consist of the number of pieces inspected to find a given number of defectives. Here the sample size is variable and the number of defectives found is constant. For example, in samples from ten-percent defective material the number of pieces required to find four defectives on five successive trials were 19, 44, 70, 39, 31 respectively. I am going to confine myself to the relatively simple case in which the process average fraction defective is p' and n is the size of the sample required to find exactly m defectives. (The double-sampling plan mentioned above is not covered by this if a second sample is started only if the first sample contained more than three defectives: I am assuming that in every case the inspector continues until he finds nine defectives if $m = 9$.)

The fundamental distribution law used here is well known, being connected with the classical ruin-of-gamblers problem. The actual problem dealt with here is not new either. In 1941 E. G. Olds[1] in a brief paper examined the distribution of the number of drawings required to find a given number of defectives in drawings without replacements from a finite lot. The following year C. E. Dieulefait[2] found a limiting form of this distribution as the lot size increases indefinitely. My present remarks were incited by an examination of some results of J. B. S. Haldane[3,4] on a method of estimation of biological populations.

None of these papers dealt directly with the question here considered. However, shortly after the appearance of Haldane's notice of his results[3], M. L. Girshick, F. Mosteller, and L. J. Savage[5] examined the general question of unbiased estimates of the population fraction defective and included an interesting remark on the uniqueness of Haldane's estimate. As a final remark, Olds says, "As far as methods of sampling inspection are concerned, the one implied in this note has little to recommend it."

For myself, I do not want anybody to infer that I am recommending the replacement of attributes sampling using fixed sample size by the method under discussion. Rather, my objective is to examine this type of attributes sampling from the standpoint of statistical quality control so that more readers of *Industrial Quality Control* can form a rational judgment of its merits.

In the theory on which the following discussion is based (see the appendix for more technical details), it is assumed either that samples are taken with replacements from small lots or that lots are large enough so samples taken without replacements will behave effectively as if they had been taken with replacements. Of course, if samples are being taken from a process, the lot being sampled is effectively infinite.

As Haldane shows, the quantity $\frac{m-1}{n-1}$ is, on the average, equal to p'. Thus for the five n's listed above, the five estimates are 3/18, 3/43, 3/69, 3/38, and 3/31, or 0.169, 0.071, 0.043, 0.079, and 0.097 respectively. This shows that such estimates are subject to considerable sampling fluctuations which should not be surprising since the average sample size to obtain four defectives is only 40. (The 3 σ limit lines on a p-chart for samples of 40 from ten-percent defective supply fall at zero and 24 percent.) Therefore, to judge the reliability of such estimates or to place limit lines on a control chart for successive values of $\frac{m-1}{n-1}$, it is necessary to have some information on the distribution of this quantity in samples. Though one can find an exact expression for $\sigma^2_{\frac{m-1}{n-1}}$ that is not too difficult to evaluate for small m's, it appears that for smaller m's and (p')'s the distribution of $\frac{m-1}{n-1}$ is not close to normal and is not easily approximated in any simple fashion. (Haldane's approximation for $\sigma^2_{\frac{m-1}{n-1}}$ is not close for such m's and (p')'s either.)

On the other hand the distribution of n/m is much more satisfactory to work with, being rather well approximated by one of the standard frequency functions known either as Pearson's type III or as the Γ-distribution which is tabulated.[6,7] This means that one can put working control limits on sample values of n/m which serve the same purpose as those on p-charts. If m is kept fixed, one might just as well simply plot sample n's.

To make a control chart for sample (n/m)'s we note first that n/m is an unbiased estimate of $1/p'$; i.e., on the average in random samples n/m is equal to $1/p'$.

(In general the average of $1/X$ is not the reciprocal of the average of X.) Then, next, $\sigma'_{n'm} = \frac{\sqrt{1-p'}}{p'\sqrt{m}}$. If one is plotting n's with m fixed, one uses $\bar{n}' = m/p'$ and $\sigma'_n = \frac{\sqrt{m(1-p')}}{p'}$.

By use of the tables for the type III or Γ-frequency function, one can use exact percentage control limits; but an examination of these tables shows that if m is four or more and p' is not more than 0.5, the proportion of sample (n/m)'s or n's falling outside of the 3σ control limits by chance is not more than 1.1 percent, assuming the process is controlled. (It is to be remembered that for p-charts with smaller n's and (p')'s the proportion included between the 3σ limits is not 99.7 percent either.) Even for smaller m's this fraction outside the 3σ limits has an extreme value of about 1.9 percent, supposing that p' is not actually zero.

As an example consider the following set of the first 25 randomly drawn values of n from a process with $p' = 0.05$, using $m = 4$: 58, 155, 155, 84, 91, 87, 32, 54, 92, 94, 70, 75, 152, 83, 103, 77, 80, 27, 39, 75, 122, 54, 64, 42, 104. Using the standard value $p' = 0.05$ the center line for n would be set at $4/.05 = 80$. Since $\sigma'_n = \frac{\sqrt{4(0.95)}}{.05} = 38.99$ and $80 \pm 3(38.99) = 197.0$ and -37.0, the limit lines are set at 197 and 4. (See Fig. 1.)

On the other hand, if one were using these 25 values to test the process for control (no standard being given or assumed), the procedure would be as follows: The center line is set at $\bar{n} = \frac{2069}{25} = 82.8$. The limit lines are set by estimating p' as $\frac{25 \times 4}{2069} = 0.0483$ and calculating $\frac{3\sqrt{4(0.9517)}}{.0483} = 121.2$. The limit lines then are drawn in at 204.0 and 4 and since all sample points fall inside it may be assumed that the process is in control.

With regard to the estimate of p', note that it was actually obtained for $m = 100$ with $n = 2069$. The σ' for this n is $\frac{\sqrt{100(0.95)}}{.05} = 194.94$ and the 3σ limits for such n's ($m = 100$) are 1484.2 and 2653.8. Thus, the corresponding extremes for estimates of p' obtained with $m = 100$ are 0.0377 and 0.0674. For comparison with the accuracy of estimation of p' by the use of an ordinary p-chart, if a fixed sample of 2000 is used ($n' = 2000$ with $m = 100$), $3\sigma_{p'} = 3\sqrt{\frac{0.05(0.95)}{2000}} = 0.0146$ and $p' \pm 3\sigma_{p'} = 0.0354$ and 0.0646.

The principle of combination of the n's and m's used above can always be applied to independent samples. Thus, if in one sample from a process, it took exactly 90 pieces to find four defectives and in another independently drawn sample exactly 130 pieces to find six defectives, one may consider that it took exactly 220 pieces to find ten defectives and an unbiased estimate of $1/p'$ on this information is $\frac{220}{10} = \frac{1}{.045+}$.

One naturally does not expect very accurate estimates by the use of small m's. With very small (p')'s one must use small m's unless large n's can be tolerated;

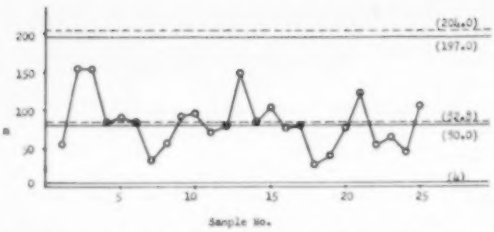

Figure 1—**Twenty-five Values of n Randomly Drawn from a Process with $p' = 0.05$, $m = 4$**

and just as in the case of the small p's in ordinary p-charts, one usually will not estimate p' at all closely for samples of ordinary size.

There is one interesting difference between estimates from small but fixed m's and variable n's and those found from smaller but fixed n's and variable fractions defective. I will illustrate this for $p' = 0.05$. First for a single sample with $m = 4$, $\bar{n}' = 80$ the 3σ limits for n, 4 and 197, give the extreme estimates of p' as one and 0.0201. On the other hand, using $n = 80$, the 3σ limits for p are zero and 0.1231. Thus, there is a lower limit but no upper limit (except unity) to estimates of p' made by the one method, while for the other there is an upper limit but no lower limit (except zero).

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Appendix

If the proportion of defectives in an infinite supply is p', the probability that exactly n drawings will be required to find m defectives is

$$f_n = \binom{n-1}{m-1} p'^m (1-p')^{n-m} \text{ where } n = m+1, m+2, \ldots$$

We have

$$E(n) = \bar{n}' = m/p'$$

and

$$\sigma'_n = \frac{\sqrt{m(1-p')}}{p'}$$

If

$$\mu_k = E\,[n - E(n)]^k$$

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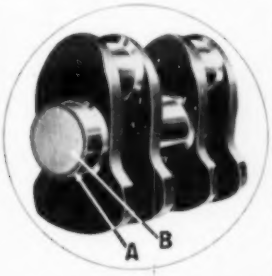

(Right) Positive Rotation Exhaust Valves, sodium-filled and stellite-faced. Scuffing action provided by their rotation prevents burning of valve lips and seats and retards formation of carbon deposits.

(Left) Tocco-hardened crankshaft journals. Note (A) glass-hard shell produced by induction hardening, and (B) extremely tough inner core.

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then the usual measures of skewness and kurtosis are

$$\alpha_3 = \frac{\mu_3}{\sigma'^3_n} = \frac{2-p'}{\sqrt{m(1-p')}},$$

and

$$\alpha_4 - 3 = \frac{\mu_4}{\sigma'^4_n} - 3 = \frac{6 - 6p' + p'^2}{m(1-p')}$$

Thus in a single sample the moment estimate of p' is m/n and in a series of independent samples with constant m it is $m/\bar{n}$. It is easy to verify that these are also maximum likelihood estimates.

The expressions for α_3 and α_4-3 suggest what Dieulefait[10] showed to be the case—that the limiting distribution for n as $m \to \infty$ is normal. But for smaller m's the Pearson type III or Γ-frequency function is much better for approximating sums of consecutive values of f_n. In fact for $p' \leq \frac{1}{2}$ (a very weak restriction for applications to sampling inspection) and $m \geq 4$ this function appears to serve rather well. That this might be expected is suggested by the facts that $2(f_{n+1} - f_n)/(f_{n+1} + f_n)$ is the quotient of two expressions both linear in n and that

$$\alpha_4 - 3 - 3/2\ \alpha_3^2 = \frac{-p'^2}{2m(1-p')}$$

is quite small for $p' \leq \frac{1}{2}$ and $m \geq 4$. (The first of these statements is equivalent to the difference equation which is the analogue of the difference equation satisfied by the type III function. The expression $\alpha_4 - 3 - 3/2\ \alpha_3^2$ vanishes for the type III or Γ-function.)

Of course, this stops somewhat short of a thorough investigation of the closeness of the approximation to f_n attained in this way. But for $m = 4$ and $p' = 0.1$ an actual calculation of the terms of f_n showed that for class intervals for n of 4–8, 9–13, 14–18, etc., the graduation given by the Γ-function with the same mean, standard deviation, and skewness as f_n never differed from the true sums of ordinates by as much as 0.001. A similar calculation for $m = 8$ and $p' = 0.25$ gave equally good results.

Actually, as Haldane observes, m/n is a biased estimate of p'. He shows that $E\left(\frac{m-1}{n-1}\right) = p'$ and suggests that $x = \frac{m-1}{n-1}$ be used as the estimator. However an investigation of the distribution of $\frac{m-1}{n-1}$ for smaller m's and (p')'s is discouraging. It seems difficult to find a satisfactory approximation function for the distribution of x or even satisfactory approximations for the moments of x for smaller (p')'s and m's. The empirical distributions of x obtained from the sampling experiments mentioned above have greater skewness and considerably greater kurtosis than for n.

It seems better for applications in statistical quality control to use the fact that n/m is an unbiased estimate of $1/p'$. Then from the type III approximation to the distribution of n/m one can estimate approximate percentage points for the sampling variation of n/m and thus for estimates of p' based on m/n.

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BUREAU OF ORDNANCE, NAVY DEPARTMENT

Vendor-consumer relations — the good will existing between the buyer and seller of a product—are dependent on a large number of intangibles. It is not proposed to discuss in this article all of the intangibles that tend to build up the desired friendly relations, but rather to consider a program to minimize and possibly eliminate some of the factors which, most frequently, adversely affect amicable relations.

My viewpoint in this article is as a member of the Electronics Technical committee of the ASQC and not as an authorized representative of the Bureau of Ordnance. The opinions expressed are, therefore, the views of this committee or my own personal ones, and do not necessarily represent the opinions and policies of the Navy Department and the Bureau of Ordnance.

Probably the most important, and certainly the most concrete, of the factors affecting vendor-consumer relations is a difference of opinion of the quality of the product. It must be assumed that any difference of opinion is due to a difference of interpretation of the specifications, drawings, standards, or requirements of the purchase order by which the consumer has indicated he wishes to purchase the product of the seller.

In most instances, the evaluation of the quality of the product as received is based on an independent interpretation of the specified requirements, and frequently the material is rejected and scrapped, returned to the vendor, or reworked by the consumer on the basis of this difference in interpretations. The outgoing inspection of the vendor has satisfied him that the product meets the vendor's standards; the incoming inspection of the consumer has satisfied him that it is not up to the standard that the consumer wishes to put in his product. Both are honest in their evaluation but different in their interpretation.

In addition, the duplication of the inspection operation, with its possible additional screening or rework requirements adds a cost to the finished product which is unnecessary and desirably might be eliminated. This elimination could occur only if the consumer were familiar with the inspection standards of the vendor, if the process average of the vendor was satisfactory to the consumer, and if the consumer was satisfied with the criteria to which the outgoing product was inspected prior to the shipment from the plant of the vendor.

Much could be accomplished toward this elimination of extra operations by the introduction of a standard criterion of quality. The introduction of such a standard, with a free exchange of information between producer and consumer, would result in increased confidence between seller and buyer, and consequently a drastic reduction of in-

*Paper presented on the program of the Sixth Annual Convention of ASQC in Syracuse, New York, May, 1952.

spection costs if mutually acceptable standards were adopted.

The Electronics Technical committee for some time has been studying the introduction of a standard criterion of quality based on a mutually acceptable, but written, interpretation of the specification requirements and including a determination of the seriousness of certain defects. It was hoped that the adoption of such a standard would permit the elimination of receiving inspection by the consumer without reduction of assurance of quality in the end product upon appropriate certification by the vendor of conformance to the mutually agreed upon standard.

The committee became interested initially because of the nature of the electronics industry. The fundamental components of the entire industry are largely composed of standard items such as resistors, capacitors, transformers, tube sockets and tubes, and a large number of these standard components are used by a great variety of consumers throughout the industry.

To permit the greatest utilization throughout the industry, the proposed standard would have to be acceptable to both the vendor and the consumer. Free exchange of information on process averages, including observed defects, must be anticipated.

The question has been well-raised as to who should undertake the introduction of such a standard. Certain associations of manufacturers have a wide interest in the field. Technical societies of various categories cover the field of a large number of products and manufacturers, and in general are less sensitive to industrial pride and prestige with its barriers to full understanding and open support of a nation-wide program. ASQC, in the position of a technical society, is even less restricted by normal trade barriers since the membership represents a greater cross-section of industry, and of management and operation, than most technical societies.

The committee has been advised by counsel that no infringement of existing laws was apparent in this activity and that we were within the scope of the constitution and charter of ASQC.

In the belief that it was essential that the industry as a whole participate in any plan to establish a uniform criterion of quality, a letter and questionnaire was sent out in the fall of 1951 to a randomly selected

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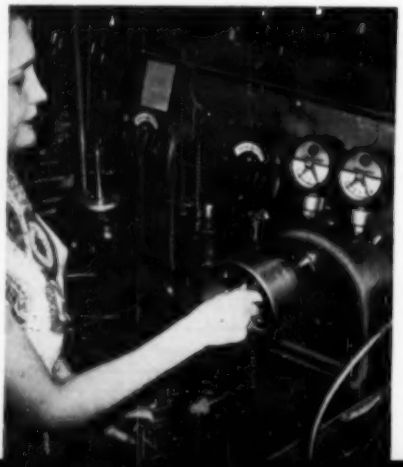


sample of the electronics industry. This letter briefly outlined the plan presented in this paper and the questionnaire was designed to determine the interests of the addressees in the program. Points covered were:

a. Buyer or seller
b. Type of components
c. Reaction to proposal
d. Participation
e. Name of individual to represent company

The response to the questionnaire was quite favorable. The return of questionnaires was approximately 22 percent as compared with the usually expected rate of return between five percent and ten percent. Eighty-four percent of the replies were favorable, three percent unfavorable and 13 percent undecided, no longer in business, or for some other reason unable to participate.

The committee was also advised informally that the questionnaire had been the subject of extensive discussion among various members of the industry, including even manufacturers who did not return the questionnaire. It is reported that these discussions were, in general, favorable.

As the next step in the program, representatives of the manufacturers and industries replying to the questionnaire, along with representatives of trade associations which exhibited an interest in the proposed program, were invited to meet in New York in March, 1952, for a mutual consideration of the implementation of a plan for a standard criterion of quality on a limited basis.

The committee and its technical advisers have considered that the minimum elements of an acceptable standard which must be established before the plan can be introduced, even on a limited and trial-run basis, are:

a. A classification of defects
b. The use of a recognized sampling plan
c. An acceptable quality level (AQL)
d. A lotting plan adaptable to sampling techniques
e. Process average information at the producer's plant

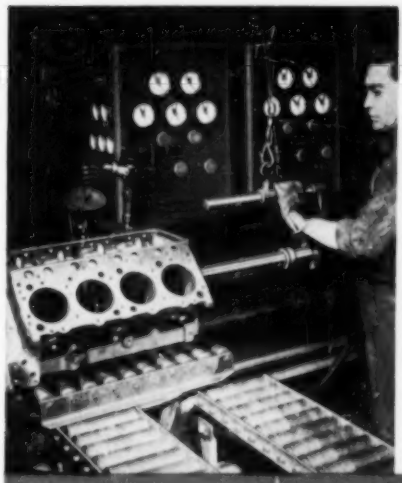
The classification of defects will of necessity be sufficiently broad to cover a large portion of the uses of a

particular component within the industry. It is not foreseen that all characteristics which might be defective can be listed, since the use of this component in certain equipments may stress the importance of a characteristic which is relatively unimportant in the more normal uses of the component. The classification of defects is, therefore, important to advise the consumer of those characteristics which have been inspected by the manufacturer, and to permit the consumer to devise an acceptance inspection plan for those characteristics deemed peculiar to his product. It has been estimated that approximately 95 percent of the uses and applications of resistors, for example, could be covered by a general classification of defects. The balance of the industry could be covered by the listing of a few additional characteristics or a minor number of changes in the classification, and these additions or changes might be accomplished by the terms of the purchase order. In any event, the incoming inspection of the consumer could be restricted to examination of the shipment for those characteristics which were peculiar to the end product of the consumer. The vendor would certify that such a classification of defects had been used.

Even if the consumer were not willing to forego all incoming inspection, both the vendor and consumer would be using the same criteria for inspection as listed in the classification of defects. Certainly no ill effect on vendor-consumer relations can be expected if the same standard is used by both. A normal result of such duplicate inspection, where the certification of the vendor is confirmed by the findings of the consumer, is a reduction in the amount of the consumer incoming inspection.

The utilization of a recognized sampling plan approaches a more controversial phase of the plan. Some manufacturers use the Dodge-Romig sampling plans. Others prefer MIL-STD-105A because of its wide use by the armed forces. The RTMA has prepared and is considering the adoption of another set of sampling tables. Since all of these sampling tables achieve an end result which is identical, the different sampling tables in use do not appear to present an insurmountable difficulty, and in some instances, the different tables have been considered as only a minor factor. The vendor certification

... in the Automotive Industry



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should, however, include for the information of all, a statement of which table was used.

The heart of the entire matter is the acceptable quality level or fraction defective on which the sampling plan is based and to which the vendor is willing to certify that his product conforms. All of us recognize that no sold product and no bought product is 100 percent perfect. Hence, we have outgoing inspection and incoming inspection. Those of us who have had experience with 100 percent inspection under these two conditions recognize that such inspection is approximately 85 percent efficient. We have, therefore, accepted a calculated risk of a certain percentage of defectives and an AQL for a product merely places on the record the recognition of this calculated risk. Sampling plans, allowing a known fraction defective to pass, are surprisingly, in some instances, more stringent in their limitations of risk than less formal inspection plans, including 100 percent inspection. The vendor's certification should by all means include a statement of the AQL to which the product conforms.

Some variation in the acceptable quality level is foreseen. For example, military products may require a higher quality level than routine commercial products. Exceptionally high quality levels could be the basis for a price differential.

The lotting plan is not a part of the proposed vendor certificate, but is an underlying condition which must be present in the contractor's plant to permit the use of sampling techniques. Lot sizes for acceptance sampling may be based on a day's production, a given number of units, or any other criterion which meets the requirement of homogenous production. The lotting plan may, of necessity, have to vary not only with the component but also with the various manufacturers of the same component.

Process average information, either in the form of a statement of fact, a control chart, or a histogram, will be necessary for the consumer to evaluate adequately the calculated risk inherent in the sampling plan. Any published information on the use of operating characteristics for sampling plans makes it obvious that the risk of accepting a single lot is too great to ask that a consumer assume such a risk. Coupled, however, with process average information, this risk is greatly reduced, and is small enough to be acceptable.

Those of you who are familiar with sampling techniques will agree that, with the five pieces of information mentioned, it would be a simple matter to evaluate the risk of accepting a shipment of material without incoming inspection, or to plan a greatly reduced inspection if the material was not entirely in accord with some special requirements. If full incoming inspection is still considered desirable, the reduction of the area of disagreement between vendor and consumer is drastic if the standard and the vendor's certification provide a common basis for the consumer's evaluation.

What then are the obstacles to the introduction of such a plan? The size of the task is an appreciable one—fortunately it can be implemented bit by bit. It is envisaged that each separate classification of defects will be a form of standard. When drawn up and approved by the major portion of a segment of industry, it can be filed with the Standards group or with ASTM as an approved standard, and each manufacturer within that segment of industry can begin its use.

Duplication of efforts of other groups will effectively hinder the implementation of such a program. The Electronics Technical committee of ASQC has invited the participation of every interested group in the promulgation of this plan. It is not believed that there is currently any duplication of the efforts of another group, and it is hoped that the interlocking membership of some of the technical committees will prevent its occurrence.

Occasionally the fear is expressed that punitive or police action will be an integral part of such a plan. There is no more need to fear this approach than is currently in effect in certain other products. The committee and the Society consider that the service we can render consists of proposing the standard for adoption after it has been developed by the industry. There are no police actions required to enforce a standard if it is necessary and this standard of quality is just as necessary for the further simplification of some of our industrial problems as other adopted standards now in use.

Figure 1 is a suggested form incorporating the required information on a certificate by the vendor or producer of a product. Those of you who are quality engineers realize the adequacy of this information to simplify some of your most pressing problems.

Various committees can be established to assist you or your segment of industry in working out the standards applicable to the fields in which you are interested. It, however, is distinctly up to you as representatives of that particular segment to take the initiative and to participate in the formation of a standard criterion of quality for your use. Two such groups were formed as sub-

CERTIFICATION OF QUALITY

THE PRODUCT SHIPPED HEREWITH HAS BEEN INSPECTED AND ACCEPTED IN ACCORDANCE WITH THE FOLLOWING REQUIREMENTS:

PRODUCT _____ (NUMBER) _____ (NAME) _____ (SPECIFICATION)

ASQC STANDARD _____ LOT SIZE _____ SAMPLE SIZE _____

SAMPLING PLAN USED _____ AQL _____

DEFECTS OBSERVED IN SAMPLE: (SHOW DEFECT AND RATE OF OCCURRENCE)

	CRITICAL	MAJOR	MINOR
	0	#101 2 #113 1	#201 1 #204 1 #207 2
PROCESS AVERAGE (FOR LAST 10 LOTS)	____%	____%	____%

DATE _____ CHIEF INSPECTOR _____

Figure 1—**Sample Certification Form**

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OUTSIDE DIA. FROM 0" TO 48"

NUMEROUS MODIFICATIONS INCL. FOR CLOSE SHOULDER WORK

3 DIAL GROOVE GAGES

TO CHECK:
DIA. OF INTERNAL GROOVES AND RECESSES (FOR TRUARC AND O RINGS)

DIAL GROOVE LOCATION GAGES

TO CHECK:
LOCATION OR DISTANCES OF INTERNAL GROOVES

4 DIAL PITCH DIAMETER GAGE

TO CHECK:

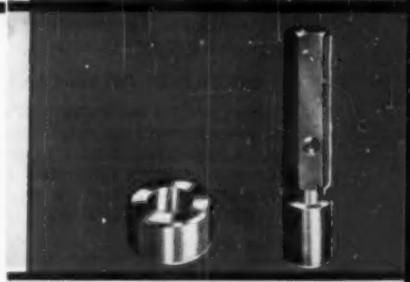
PITCH DIA. OF SPLINES & GEARS

(ROLLS REMOVABLE & INTERCHANGEABLE)

5 PLUG & RING GAGES

TO CHECK:

INTERNAL DIMENSIONS
EXTERNAL DIMENSIONS



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committees at the March meeting in New York—one for composition resistors and one for small fixed condensers.

Allow me for a moment to revert to my status as a representative of the Bureau of Ordnance. The proposed plan for the introduction of a standard criterion of quality has been considered in the Bureau, and the Bureau is willing to consider revision of existing techniques of Ordnance Inspection to the extent warranted by an appraisal of the ultimate form of the plan as implemented. As outlined herein, the Bureau of Ordnance is willing to accept the classification of defects as a fundamental standard and to base its acceptance inspection on that standard, with such modifications, (expected to be minor) which the requirements of ordnance material may necessitate. Sampling plans have, for some time, been a recognized inspection technique of the Bureau of Ordnance, and our inspection would be based on MIL-STD-105A. Acceptable quality levels have already been established for normal inspection.

Fundamental Principles of Sequential Analysis*

IRVING W. BURR

Purdue University

HISTORY AND INTRODUCTION

Work by Harold Dodge and Harry Romig, and Walter Bartky on double- and multiple-sampling, respectively, supplied the background to the development of sequential analysis. Experimentation in successive stages was also suggested and used by Harold Hotelling and P. C. Mahalanobis.

The problem of sequential analysis first arose in the Statistical Research Group of Columbia University in some comments of Captain G. L. Schuyler of the Bureau of Ordnance. Following up this idea, Milton Friedman and W. Allen Wallis conjectured that sequential procedures might be developed having as good control of errors in misclassifying lots, but which would require less average inspection. This was brought to the attention of the late Abraham Wald, who then developed the probability ratio sequential test, worked out the general theory of the test, and applied it to many important problems. Hence, sequential analysis is in large part a contribution of Abraham Wald.[2]

Since 1945 there has been a host of articles deepening the theory and applying the sequential approach to many problems such as that of statistical estimation. See, for example, the references in the index to Vols. 1 to 20 of the *Annals of Mathematical Statistics*.

Fundamentally the aim of sequential analysis is to obtain decisions of requisite security on the basis of a smaller average number of tests or determinations than is possible with even the very best single-sampling plans possible. (The saving is often as much as 50 percent at critical levels of quality and considerably more at very good or very poor quality.) The aims of this article are to discuss briefly the fundamental principles of sequential analysis and show how these work out in the various cases in practice. Further, we want to show how unified and comparatively simple the sequential plans are.

DEFINITION OF SEQUENTIAL ANALYSIS

In general, a sequential test is one in which, after each measurement or determination, we may either accept a hypothesis (or lot or process), reject the hypothesis, or request additional evidence. As such, the sample size is, in general, a variable. Sometimes it is very small; at others it is quite large.

*Paper presented on the program of the Sixth Annual Convention of ASQC in Syracuse, New York, May 1952.

Single and double sampling are special cases of sequential analysis, in which neither acceptance nor rejection is possible until n (or n_1) pieces are measured or tested. Thus the only decision on the pieces less than n is a request for more evidence.

The sequential test terminates according to definite rules, that is, when sufficient evidence for a decision has been accumulated.

A GENERAL APPROACH TO SAMPLING

For either general sequential sampling or single sampling we could proceed as follows: Decide upon one level of quality or performance, which we may for the present think of as "good" quality. Let this be q_1 and the hypothesis that the quality is at q_1 be H_1. (The quality measure, q, could be average, standard deviation, fraction defective, etc.) Decide upon a second quality, q_2, which we will regard as "bad" quality. Let the hypothesis that the quality is q_2 be called H_2 or the "alternative" hypothesis. Also, for the present, we suppose that the only possible quality levels are just these two. Later we shall see that plans based on just these two work well for all other levels.

Next we must consider the risks or probabilities of erroneous decisions. If the H_1 is true, that is, the quality is at q_1, we might erroneously conclude that the quality is at q_2 and decide to reject H_1. This would be called an "error of the first kind." Let the probability of this error be α; that is, if the quality is q_1 the probability of rejection is α. Similarly, if H_2 is true, that is, the quality is at q_2, we can erroneously accept H_1, that is, conclude that the quality is q_1. This is called an "error of the second kind." Let the probability of committing such an error when H_2 is true be called β.

Now, in classical statistical tests, main attention was given to errors of the first kind. Tests were set up with fixed, small risks α, so that the hypothesis, H_1, would be only rarely rejected when true. On the other hand, the quality might be a long way from q_1, and we might easily still accept H_1. As a consequence, attention began to be paid to errors of the second kind. Early work, especially by E. S. Pearson and J. Neyman, led to the development of tests which had a fixed "error of the first kind," α, and which succeeded in minimizing errors of the second kind for one, many, or all possible alternatives. These were largely for single samples; that is, for a fixed sample size.

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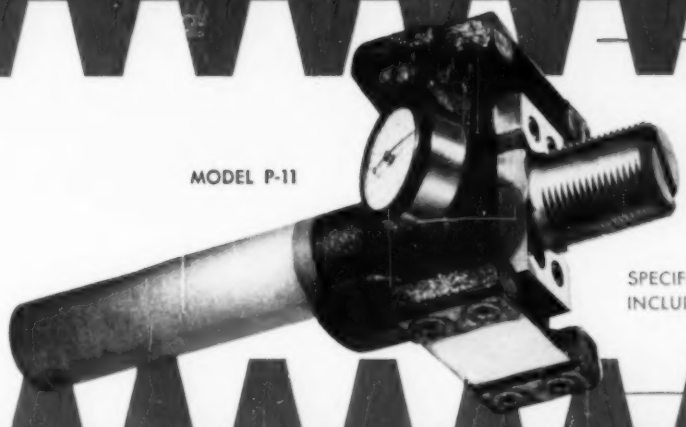

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Sequential sampling plans are "better" than these "most powerful" tests in the following sense: Suppose we take such a best single-sampling plan with given α and n, then it is possible to find a sequential plan with the same α and with its maximum average sample size $\bar{n}$, equal to n, but which has uniformly smaller probabilities of errors of the second kind. In this sense then there are sequential plans which are more powerful than the most powerful single-sampling plan.

Given the four quantities q_1, q_2, α, β it is possible in many cases to find single, double and sequential plans to meet these conditions. Always keep in mind that to compare two sampling plans as to cost and usefulness, we must first make sure that they supply comparable protection: that is, have similar operating characteristic curves. If the four quantities just given are the same, then the OC curves will be sufficiently alike for sound comparison.

Knowing that the OC (i.e. protection) curves are comparable, then we can look at the ASN, average sample number, (i.e. cost) curves. We can draw ASN curves for single-sampling (a straight line) or double- or sequential-sampling plans. The latter tend to give the greatest saving over single sampling for quality outside of the interval between q_1 and q_2.

THE SEQUENTIAL PROBABILITY RATIO TEST

Consider now Wald's basic sequential test. We form the ratio of the following probabilities from a sample of n:

P_{2n} = probability of the observed sample if hypothesis H_2 is true

P_{1n} = probability of the observed sample if hypothesis H_1 is true

Now the test is as follows:

If $P_{2n}/P_{1n} \leq B$, we accept H_1

If $P_{2n}/P_{1n} \geq A$, we reject H_1

If $B < P_{2n}/P_{1n} < A$, we need additional evidence.

The first makes sense because in this case we have worked until P_{2n} is so much smaller than P_{1n} that the hypothesis H_2 is so much poorer an explanation of the observed sample than H_1 that we are justified in accepting H_1. In the second case we have continued until the P_{2n} is so much greater than P_{1n} that H_2 is a sufficiently better explanation of our observed sample than is H_1, that we justifiably accept H_2 and reject H_1.

The A and B used in the test are strictly determined by the type of case involved and by the risks α and β. In practice, however, α and β alone would determine A and B very closely. In fact, in general, we set

$$A = \frac{1-\beta}{\alpha}, \qquad B = \frac{\beta}{1-\alpha} \tag{1}$$

Sequential plans with A and B so chosen actually will not have precisely the requested α and β, but will instead have risks, say α' and β'. It can be shown, however, that

$$\alpha' \leq \frac{\alpha}{1-\beta} \qquad \beta' \leq \frac{\beta}{1-\alpha}$$

$$\alpha' + \beta' \leq \alpha + \beta.$$

Although it could still happen that one of the true α', β' obtained by using A and B as defined in (1) is a tiny amount above the respective α or β, their sum is always less than or equal to the sum of the desired risks $\alpha + \beta$. Since the possible excess amount of risk of an α' or β' is extremely slight in practice, we always do define A and B by Eqs. (1).

Working out the sequential plan for a special case depends upon the calculation of the ratio, P_{2n}/P_{1n} and comparison to A and B. In a number of important special cases, as we shall see, this can be simplified into a test with appropriate acceptance and rejection numbers for each sample size.

In many cases also, it is possible to find as many points on the OC curve (i.e. besides $[q_1, 1-\alpha]$, $[q_2, \beta]$) as we wish. Moreover, we find that although, technically, the plan was only worked out for the two quality levels, q_1 and q_2, it does give an OC curve making good sense throughout. Thus, as quality tends from q_1 toward q_2, the probability of acceptance (of H_1) decreases steadily from $1-\alpha$ to β. Beyond q_2 it rapidly approaches zero, and beyond q_1 in the other direction, it rapidly approaches one, or certainty. This is just what we would ask for. We only asked for the two points, but got all this too—a clear-cut case of "eating your cake and having it too."

The ASN curve is available, too, for special cases. In most of these cases it tends to hit a maximum somewhere between q_1 and q_2; but even at its maximum, it is well below the n for a single sample with comparable OC curve.

One other point which bothers some people is the possibility of a sequential plan running on forever. This has been proved to have a probability of zero. Thus, the plan is sure to terminate. In point of fact, the probability of a sequential sampling plan running on beyond three times the larger of the two ASN's at q_1 and q_2 is very small. Hence, we usually only carry out the acceptance and rejection numbers about that far. Balancing such long runs are many quite quick decisions, which can even occur with $n = 1$.

A final general comment is that the probability ratio test does not depend upon our ability to handle the sampling distribution form as long as we can form P_{2n}/P_{1n}. We can form this ratio much more often than we can develop the precise single-sampling test. We can, for example, make a sequential test of means with a very wide class of populations.

COMPARISON OF CASES

We can easily handle the following cases by sequential analysis:

a. Fraction defective; hypotheses on $q_1 = p_1 < q_2 = p_2$

b. Number of defects per unit, hypotheses on $q_1 = c_1 < q_2 = c_2$

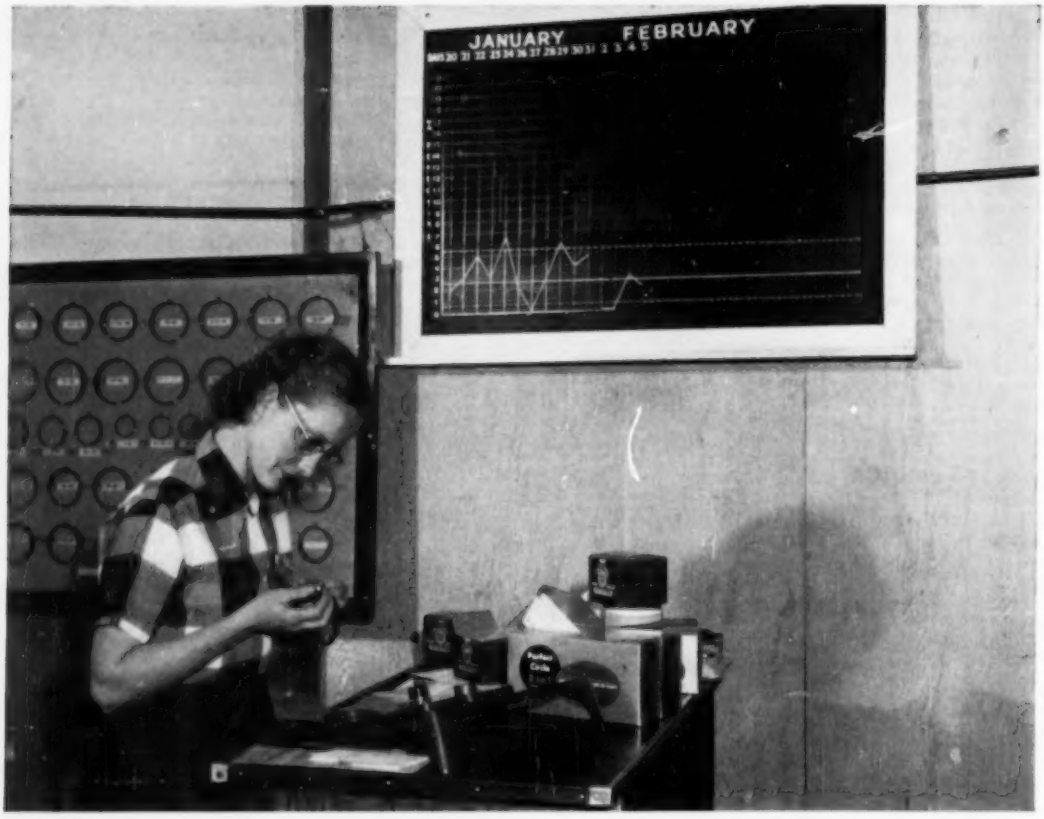
c. Mean of measurements, one-way, σ' known, normal population, hypotheses on $q_1 = m_1 < q_2 = m_2$. Assume q_1 is acceptable.

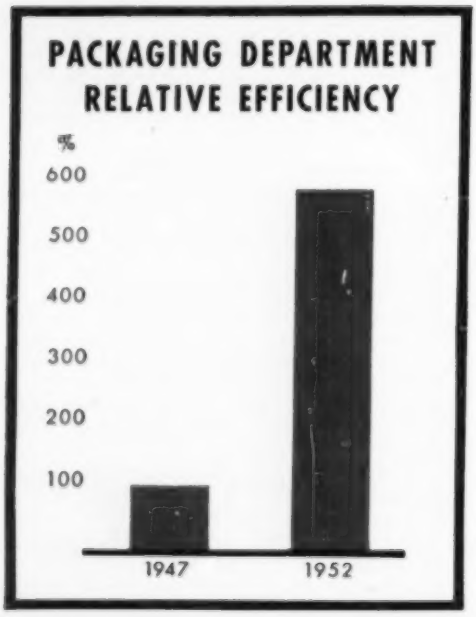
d. Mean of measurement, two-way, σ' known, normal population, hypotheses on $q_1 = m$, $q_2 = m \pm d$.

e. Standard deviation normal population, mean known, hypotheses on $q_1 = \sigma_1 < q_2 = \sigma_2$.

f. Same as *e*, but mean unknown.

These five cases may then be summarized as follows:





RESULTS THAT COUNT

Warehouse and packaging operations at Perfect Circle's Hagerstown plant perform under 100% Statistical Quality Control.

Major and minor standards verification by SQC operators in the Packaging Department has been instrumental in raising the operating standard and over-all efficiency of the department almost 500% in slightly more than five years time.

Perfect Circle PISTON RINGS

The Standard of Comparison

(1). For case *a* we use the ordinary logarithm of A and B to give a and b by

$$a = \log \frac{1-\beta}{\alpha} \qquad b = \log \frac{1-\alpha}{\beta} \qquad (2)$$

while for cases *b*—*e* we use natural logs of A and B

$$a = \ln \frac{1-\beta}{\alpha} \qquad b = \ln \frac{1-\alpha}{\beta} \qquad (3)$$

(2). The test sample criteria are as follows, all of which are steadily accumulated:

a. Total defectives, d, in n pieces.

b. Total defects, d, in n pieces.

c. Total measurements, ΣX or more easily used $\Sigma (X - A)$ (coded data), in sample of n.

d. Total deviations from m, $|\Sigma(X - m)|$ in n measurements.

e. Total variation from true mean, m, $\Sigma(X - m)^2$, in n pieces.

(3). Criteria of acceptance and rejection, at sample size n, are all, by formula, respectively, $(-h_1 + sn)$ and $(h_2 + sn)$, where $-h_1$ and h_2 are the intercepts and s is the slope of the two parallel lines. In case *d* there is a curving of the acceptance line, however, at small n's.

(4). Formulas, (Be sure to use the correct a and b from Eq. (1).)

a. $h_1 = \dfrac{b}{\log \dfrac{p_2(1-p_1)}{p_1(1-p_2)}} \qquad h_2 = \dfrac{a}{\log \dfrac{p_2(1-p_1)}{p_1(1-p_2)}}$

$$s = \left[\log \frac{1-p_1}{1-p_2}\right] \Big/ \left[\log \frac{p_2(1-p_1)}{p_1(1-p_2)}\right]$$

b. $h_1 = \dfrac{b}{\ln c_2 - \ln c_1} \qquad h_2 = \dfrac{a}{\ln c_2 - \ln c_1}$

$$s = \frac{c_2 - c_1}{\ln c_2 - \ln c_1}$$

c. $h_1 = \dfrac{b\sigma'^2}{m_2 - m_1} \qquad h_2 = \dfrac{a\sigma'^2}{m_2 - m_1}$

$$s = (m_1 + m_2)\ /\ 2$$

d. $h_1 = \dfrac{\sigma'^2}{d}(b - .693) \qquad h_2 = \dfrac{\sigma'^2}{d}(a + .693)$

$$s = \frac{d}{2}$$

Use as criterion

$$\ln \cosh \left[\frac{d\ |\ \Sigma\ (X - m)\ |}{\sigma'^2}\right] < \frac{nd^2}{2\sigma'^2} - b$$

for small n, using tables in reference (3) for ln cosh fraction.

e. $h_1 = \dfrac{2b}{\dfrac{1}{\sigma_1^2} - \dfrac{1}{\sigma_2^2}} \qquad h_2 = \dfrac{2a}{\dfrac{1}{\sigma_1^2} - \dfrac{1}{\sigma_2^2}}$

$$s = \frac{\ln (\sigma_2^2 / \sigma_1^2)}{\dfrac{1}{\sigma_1^2} - \dfrac{1}{\sigma_2^2}}$$

(5). OC curves, probability of acceptance, L

a.

$p' = 0$	$L_\infty = 1$
$p' = p_1$	$L_{p_1} = 1 - \alpha$
$p' = s$	$L_s = h_2/(h_1 + h_2)$
$p' = p_2$	$L_{p_2} = \beta$
$p' = 1$	$L_1 = 0$

b.

$c' = 0$	$L_\infty = 1$
$c' = c_1$	$L_{c_1} = 1 - \alpha$
$c' = s$	$L_s = h_2/(h_1 + h_2)$
$c' = c_2$	$L_{c_2} = \beta$
$c' = \infty$	$L_\infty = 0$

c.

$\overline{X}' = \text{low}$	$L_{\text{low}} = 1$
$\overline{X}' = m_1$	$L_{m_1} = 1 - \alpha$
$\overline{X}' = s$	$L_s = h_2/(h_1 + h_2)$ (bad for high values)
$\overline{X}' = m_2$	$L_{m_2} = \beta$
$\overline{X}' = \text{high}$	$L_{\text{high}} = 0$

d.

$\overline{X}' = \text{low}$	$L_{\text{low}} = 0$
$\overline{X}' = m - d$	$L_{m-d} = \beta$
$\overline{X}' = m$	$L_m = 1 - \alpha$
$\overline{X}' = m + d$	$L_{m+d} = \beta$
$\overline{X}' = \text{high}$	$L_{\text{high}} = 0$

e.

$\sigma' = 0$	$L_0 = 1$
$\sigma' = \sigma_1$	$L_{\sigma_1} = 1 - \alpha$
$\sigma' = \sqrt{s}$	$L_{\sqrt{s}} = h_2/(h_1 + h_2)$
$\sigma' = \sigma_2$	$L_{\sigma_2} = \beta$
$\sigma' = \text{large}$	$L_{\text{large}} = 0$

(6). ASN curves

a.

$p' = 0$	$ASN = h_1/s$
$p' = p_1$	$ASN = \dfrac{(1-\alpha)h_1 - \alpha h_2}{s - p_1}$
$p' = s$	$ASN = h_1 h_2/s(1-s)$
$p' = p_2$	$ASN = \dfrac{(1-\beta)h_2 - \beta h_1}{p_2 - s}$
$p' = 1$	$ASN = h_2/1 - s$

b.

$c' = 0$	$ASN = h_1/s$
$c' = c_1$	$ASN = \dfrac{(1-\alpha)h_1 - \alpha h_2}{s - c_1}$
$c' = s$	$ASN = h_1 h_2/s$
$c' = c_2$	$ASN = \dfrac{(1-\beta)h_2 - \beta h_1}{c_2 - s}$
$c' = \infty$	$ASN = 0$

c.

$\overline{X}' = \text{low}$	$ASN = 1$
$\overline{X}' = m_1$	$ASN = \dfrac{(1-\alpha)h_1 - \alpha h_2}{s - m_1}$
$\overline{X}' = s$	$ASN = h_1 h_2/\sigma'^2$
$\overline{X}' = m_2$	$ASN = \dfrac{(1-\beta)h_2 - \beta h_1}{m_2 - s}$
$\overline{X}' = \text{high}$	$ASN = 1$

d. Not available

e. $\sigma' = 0$	$ASN = h_1/s$
$\sigma' = \sigma_1$	$ASN = \dfrac{(1-\alpha)h_1 - \alpha h_2}{s - \sigma_1^2}$
$\sigma' = \sqrt{s}$	$ASN = h_1 h_2 / 2s^2$
$\sigma' = \sigma_2$	$ASN = \dfrac{(1-\beta)h_2 - \beta h_1}{\sigma_2^2 - s}$
$\sigma' =$ large	$ASN = 1$

All of these formulas are quite readily obtained from the probability ratio definition by using the appropriate population functions. Case *f* is not so easily handled, but it turns out that we should use as criteria

$$-h_1 + (n-1)s, \; h_2 + (n-1)s$$

where the h_1, h_2, s are just as given for case *e* and where the criterion is $\Sigma(X - X)^2$. Note the large similarity in criteria formulas and OC and ASN curves.

Special approaches may readily be worked out to handle significance of difference between two proportions and between two means. These are also of much use especially in the laboratory.

APPLICATIONS

The calculations of criteria of acceptance and rejection are not especially difficult to work out especially with appropriate tables and machines. Reference (3), part 2, contains a large number of special cases all worked out for case *a*. Reference (4) has a set of cases worked out for cases *c* and *d* if $m_2 - m_1$ or d equal σ' and $\alpha = \beta = 0.10$.

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1. Wald, A., *Sequential Analysis of Statistical Data: Theory*, a report submitted by the Statistical Research Group, Columbia University, to the Applied Mathematics Panel, National Defense Research Committee, September, 1943. A formerly restricted report on the theory.

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4. Burr, I. W., "A New Method for Approving a Machine or Process Setting — Part III," *Industrial Quality Control*, Vol. VI, No. 3, November, 1949, pp. 13-16.

5. *Tables to Facilitate Sequential t-Tests*, National Bureau of Standards, Department of Commerce, Applied Mathematics Series 7, 1951. This reference covers the case not dealt with in the foregoing, in which the test is on the mean, but the population standard deviation is unknown. The tables make practical applications in this case quite simple.

SUCCESSFUL THRU STATISTICAL QUANTITY AND QUALITY CONTRACTS IN CONTROL

eyelets

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stampings

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A few of the 50,000 items sold by DON and listed below may suggest something you need NOW!

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- Chinaware
- Tables and Chairs
- Floor Maintenance Machines
- Ovens (Gas-Electric)
- Towel Dispensers
- Ash Trays and Stands
- Mixers (All Kinds)
- Polishes and Cleaners
- Bar Stools
- Menu Covers
- Pots and Pans
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- Bed Linens
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- Cutlery
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- Vacuum Cleaners
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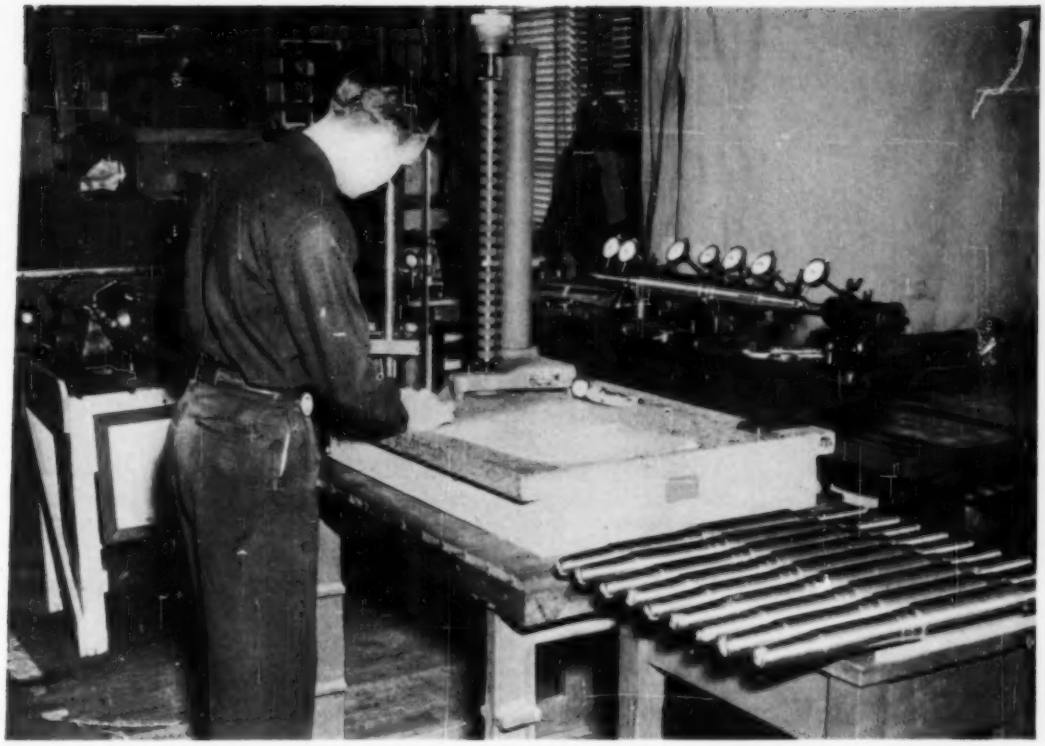


Quality Control Assures High Product Performance and User Satisfaction

In the production of De Laval equipment for agriculture and industry, precision manufacture and a well-developed system of *Quality Control* are essential to meet the requirements of continuous efficient performance and trouble-free service.

Over the years, the loyalty of De Laval users has been won and held because of our De Laval quality—controlled from raw material to final assembly.

THE DE LAVAL SEPARATOR COMPANY

POUGHKEEPSIE, N. Y.

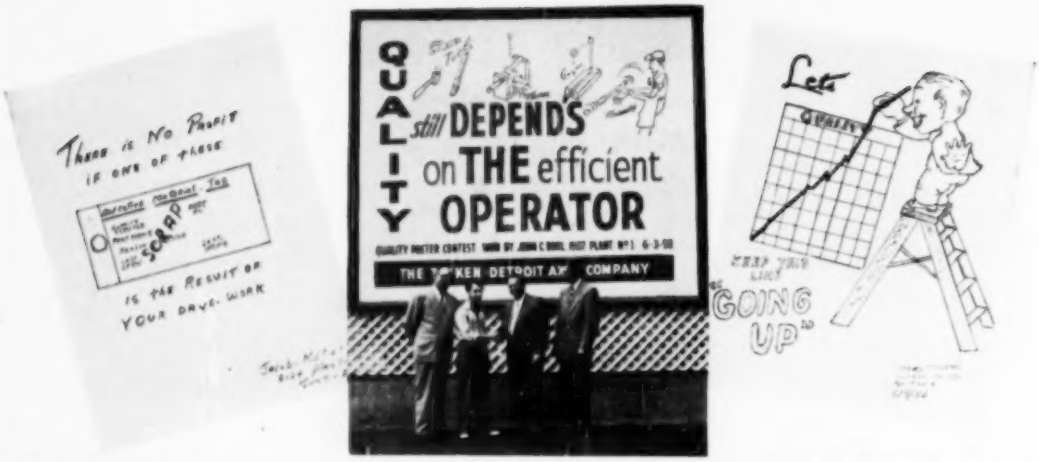


Figure 1—**Poster Contest Winners.** Center Picture, Left to Right: The Author; John Bohl, First Prize Winner; Walter F. Rockwell, President, Timken-Detroit; and William E. St. Clair, Detroit Plant Manager.

Quality Control at Timken-Detroit Axle Company

JAMES RAYER, SR.

Staff Supervisor of Quality

Something over five years ago a modern statistical quality control system was instituted by The Timken-Detroit Axle Company.

Today, as we chart our progress well into the sixth year, there can be no question but that statistical quality control has resulted in better production, improved employe morale, and substantial savings in money.

Timken-Detroit is the world's largest producer of axles for trucks, buses and tractors. In addition, it is a major producer of oil and gas heating units and of metal stampings. It now has nine plants in five states—New York, Pennsylvania, Michigan, Ohio and Wisconsin. Some of these have been added since the war, but as each has come into the organization, a quality control system has been established and the records included in the over-all study.

Applying quality control in a company whose products are so varied—we make approximately 500 different designs of axles alone involving more than 12,000 specifications—is no easy task. But an indication of how well the program has taken hold, even down at the hourly worker level, can be obtained from the results of a recent quality control poster contest.

EMPLOYE POSTER CONTEST

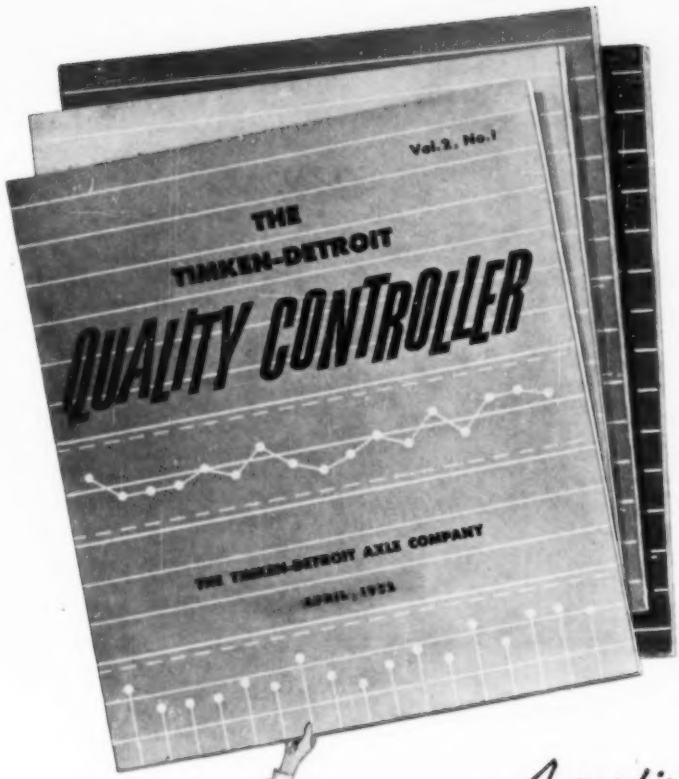
The decision to conduct a poster contest among hourly-rated employes was not motivated by the need for more employe understanding and cooperation. Rather, it was done in recognition of the fact that "selling" quality control in an organization is a continuing job. A relaxation of effort is almost immediately accompanied by a climb in the cost curves. Also, it was felt that our employes might supply us with ideas more applicable to our individual problems and more interesting to their fellow workers.

The poster contest was open to all hourly-rated employes, a total of 9,481 in the nine plants, and their families. There was no restriction on the number of entries by any individual. Prize money totalled $2,250, with a grand prize of $500, and second and third prizes of $250 and $150, respectively. In addition, there were 18 other prizes of $100 and $50 each for the best entries in each of the nine plants.

We announced the contest with a "teaser" plant poster, which simply said "Watch for Friday, May 23" and which was posted two weeks in advance of the date. As might be expected, this created considerable interest and some rare rumors circulated. The suspense was lifted on May 23 with another poster advising all employes of the contest, and telling them to read The Timken-Detroit *Quality Controller* for details. This is a publication of the quality control division which is distributed in pay envelopes so as to reach every employe.

At the conclusion of the contest on June 7, 1952, 862 entries were collected from boxes conveniently located near time clock courts. This was an over-all return ratio of 9.09 percent, the high being set by the New Castle plant, where 14 percent of 1,300 employes submitted entries.

Judging was handled by an outside agency purely on the basis of aptness of thought, and recognition of the winners was not limited to the prizes. Photographs and stories about the plant winners were published in plant city newspapers and the posters of the three top winners were blown up to billboard size and posted at the main entrance of the Detroit plants. Thoughts expressed in the entries will be used for plant posters for some time.



A continuing program at

TIMKEN-DETROIT

At The Timken-Detroit Axle Company both management and employees are kept Quality-Control-conscious by this interesting and informative publication. Distributed regularly to all employees in their pay envelopes throughout Timken-Detroit's nine great plants, each pocket-size issue is devoted entirely to the subject of Industrial Quality Control—what it is, how and why it is used, and its importance to every man and woman in the Company. Here, indeed, is tangible evidence that The Timken-Detroit Axle Company is *promoting and practicing* Industrial Quality Control.

TIMKEN *Detroit* AXLES

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DETROIT 32, MICHIGAN

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PLANTS AT: DETROIT AND JACKSON, MICH. • OSHKOSH, WIS. • UTICA, N. Y. • ASHTABULA, KENTON AND NEWARK, OHIO • NEW CASTLE, PA.

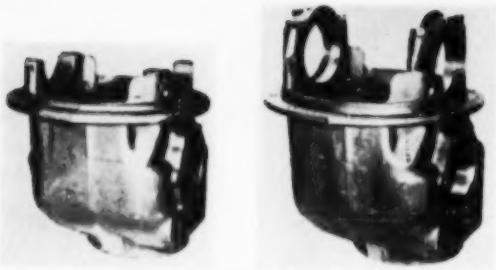

Figure 2—**Carrier Mounting Casting (Left) and Finish-Machined (Right)**

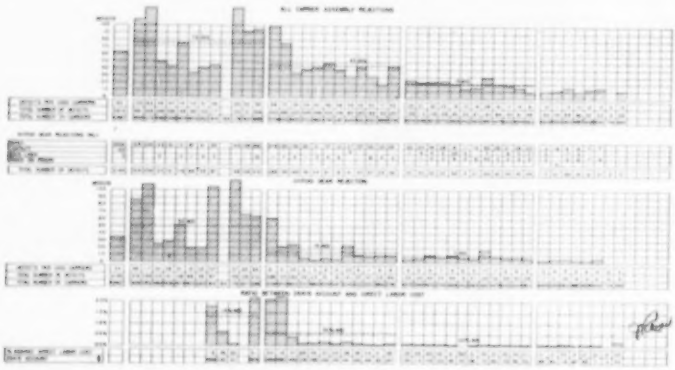

Figure 3—**Customer "A" Quality Summary**

GETTING STARTED

So it is with confidence, born of the interest in our program at all levels, that we work well into our sixth year of statistical quality control. This was not always so, for initiating a full-scale quality control program in an industry presents many problems. Of course, there is the experience of others from which to draw, but each company presents its own unique difficulties and each system must, of necessity, grow out of trial and error. This was certainly true at Timken-Detroit and is still true to some extent today.

We are satisfied with our principles and our basic system, but we must remain flexible enough to meet the challenges presented almost daily by production changes, by design changes, by new products.

One of our earlier successes with quality control techniques as applied to a high production part, was in machining a two-speed carrier mounting shown in Fig. 2.

Turning, drilling, milling, reaming, tapping, and precision boring operations complete the machining of this carrier. Cross shaft, differential, and pinion bores are sized and held in alignment on Excello precision boring machines.

An average of 5,500 of these carriers are machined each month. Scrap averages 20 carriers per month. This record is outstanding and has been maintained for almost five consecutive years.

During 1951, through August 1952, 95,246 of these carriers were built with not one complaint regarding the quality of machining. These assemblies are given a 100-percent inspection and sound test by the vehicle manufacturer. Figure 3 shows the quality performance.

This performance is outstanding in that this user customer sound-tests each assembly and reports all defects. The gear rejections tabulated are all the gearing discrepancies reported since 1949. We identify these discrepancies as rejections at the customer's first inspection.

When this job first started five years ago, eight inspectors over three shifts, were required for 100-percent inspections on carrier machining. For the past 4½ years one QC Inspector per shift measures the various controlled dimensions and plots the 23 X and R charts necessary to maintain the dimensional quality that is required. All 100-percent inspections were discontinued long ago.

This early experience at Timken-Detroit Axle, with quality control techniques, convinced us that design, adequate tooling, efficient operators, plus quality control, results in high quality at minimum costs.

Here is another example where quality control aided in producing thousands of quality, trouble-free parts. (See Fig. 4.)

Production on this gear blank runs 12,000 a month. Since quality control was started we have machined about 576,000 of these gear blanks. An average of only 25 blanks are scrapped each month. Most of these are set-up pieces.

This blank is shipped to another plant for cutting and carburizing. The only complaints received regarding the quality involved nicks and burrs. The handling was corrected and the nick complaints stopped. Constant attention to burrs has kept this complaint to a minimum.

The QC men inspect a 3-piece sample at regular intervals at each machine and plot the findings on 12 $\bar{X}$ and R and Band charts. These 12 charts indicate the quality of all the important dimensions and finished part. No 100 percent inspections are necessary.

Figure 4—**Gear Blank Forging (Top) and Finish-Machined (Bottom)**

MADE IN NEW BEDFORD FOR OVER 100 YEARS

WAMSUTTA MILLS*

MEMBER OF COTTON TEXTILE INSTITUTE, INC.

SUPERCALE SHEETS & PILLOW CASES

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*Where Quality Control has helped to build a name which has become synonomous with "Quality" - and continues to guard that reputation.

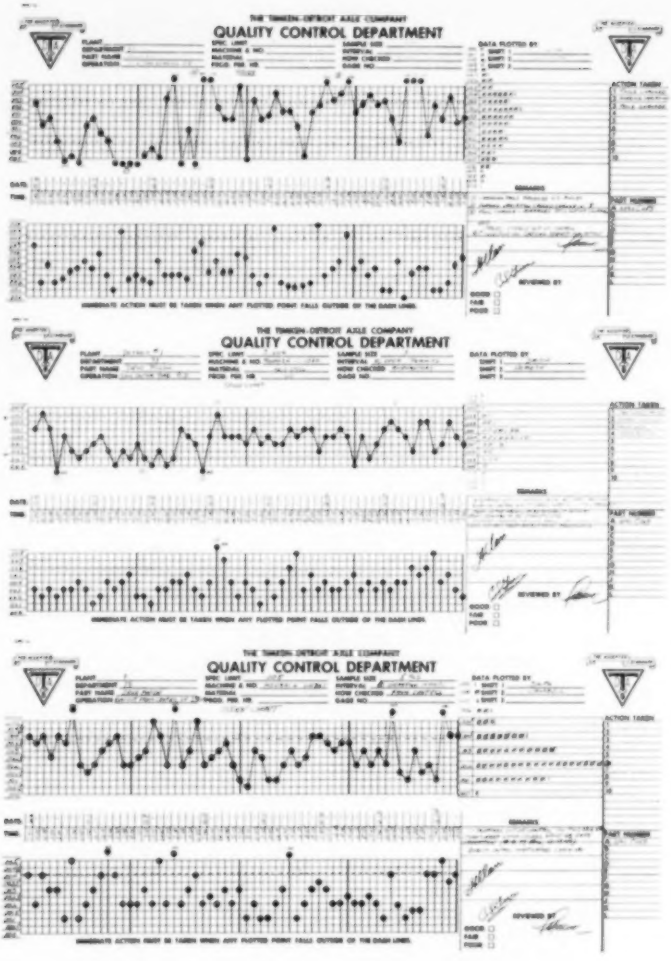


Figure 6A—**Machine Study Showing Plottings for Dimension "A" (Top), Dimension "B" (Middle) and Dimension "C" (Bottom) illustrated in Fig. 5**

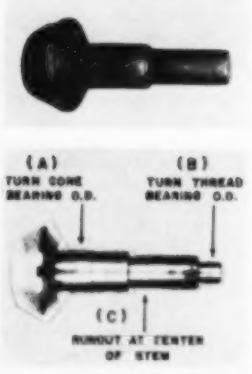


Figure 5—**Drive Pinion. Top: Forging Bottom: Turned Blank Showing Dimensions Plotted in Fig. 6**

A further example of close cooperation between engineering, production, and quality control is illustrated in the case of the turning of a drive pinion blank. (See Fig. 5.) Production on this part is 5,500 pieces per week.

During 1948, three worn out machines turning this pinion were replaced by three Monarch Monamatic turning lathes. These new lathes increased production in that several high-production drive pinions were turned in addition to the one type formerly produced.

One man runs three machines. One machine turns the head while the other two turn the stem. Turning is accomplished by a single carbide tool on the front carriage which is guided by a tracer pin moving along the contour of a steel template. However, serious problems arose when these new machines were first installed. The control charts revealed that the desired degree of dimensional accuracy couldn't be maintained.

The Monarch Company engineers worked closely with the production and quality control people. Several changes were made including modification of the template and strengthening the front slide. After these changes the improvement in the dimensional accuracy was readily noted, as shown on the control charts in Fig. 6.

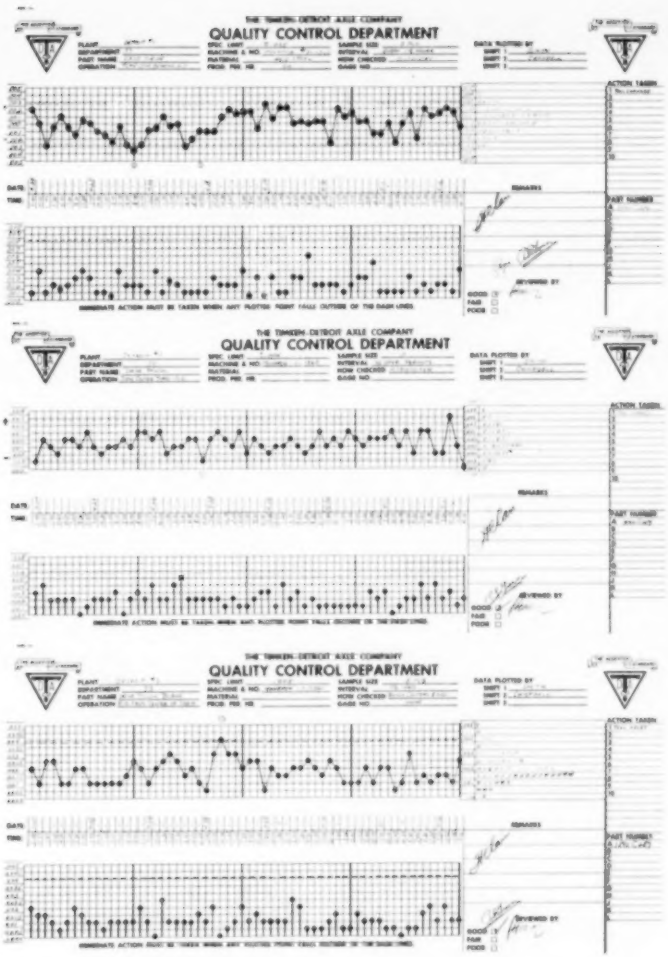


Figure 6B—**Control Charts on the Machined Dimensions in Fig. 6A After Proper Adjustments**

These and other early experiences, through which we were able to present to management proof of concrete dollars and cents savings, not only encouraged us but brought us the whole-hearted backing of the manufacturing division. It should be emphasized, however, that from the very first we enjoyed the complete support of our top management.

THE PROOF

There is no hard-and-fast method of measuring the savings effected by quality control on a company-wide basis. Too many external factors intervene, peaks and valleys in production, model changes, tool changes, etc. However, we at Timken-Detroit have from the first kept a master chart showing the percentage of saving based against direct labor on inspection and quality control, scrap, and in perishable tools. We believe examination of this chart (Fig. 7) shows graphically the effectiveness of our quality control program. Note the downward trend in all three graphs.

In inspection and quality control we have dropped from a 16.1 percent figure in 1946 to a 12.8 percent average in 1951, with the trend continuing.

The same general trend shows both in the scrap graph and in perishable tools. Scrap dropped from 6.1 percent to a low of 3.4 percent in 1950 but climbed slightly in 1951. The perishable tool chart show more "ups and downs" than the others, but the sharp decline since 1946 from 13.2 percent to the current level of 7 percent plus is clear.

Substantial savings were achieved as a result of these reduced costs. Excellent though that record is, quality summary charts on all major customers show even more startling results. Careful records are kept of all defects reported at customer's first inspection.

The Customer "B" Quality summary chart in Fig. 8 shows the combined defects for front and rear axles

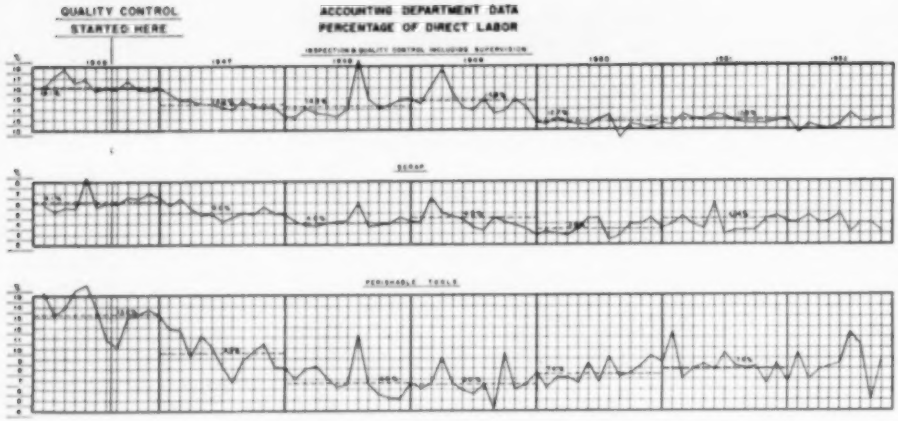


Figure 7

per 1000 axles for the period 1949 through August 1952 inclusive.

The defects per 1000 axles during 1950 jumped to seven, reflecting the introduction of new models. During 1951, the quality improved, reducing defects at customer's first inspection back to two defects per 1000 axles.

During 1952, through August, defects at customer's first inspection average 1.2 defects per 1000 axles.

A similar chart for Customer "C" (Fig. 9) shows a steady decline in axle rejections from an average of 14 defects per 1000 axles in 1949 to three defects in 1952.

The quality of Timken-Detroit Axles purchased by Customer "D" during 1952 (Fig. 10) certainly shows considerable improvement when compared with the quality during 1949. Defects per 1000 axles during 1949 averaged 43. During 1952, through the month of August, defects per 1000 axles were reduced to 12.

The upper section of the quality summary chart in Fig. 11 shows progress made since 1949 in reducing defects reaching our major customers' plants. From an average of 25 defects per 1000 axles during 1949, quality has improved to the extent that during 1952 this item is now averaging ten defects per 1000 axles. This indicates a 60 percent improvement in quality.

The lower section shows the savings resulting from the improved quality. An average of 8.6 percent of the direct labor costs was spent in 1949, to correct lack of quality. During 1952 this expenditure dropped to about 0.75 percent.

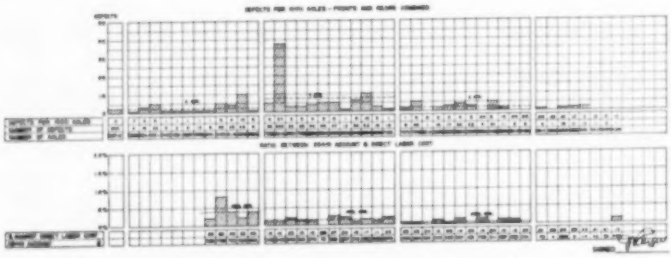


Figure 8—**Customer "B" Quality Summary**

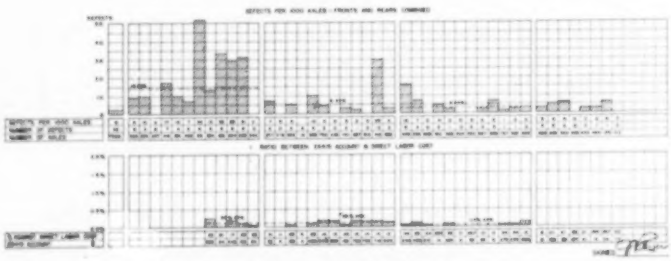


Figure 9—**Customer "C" Quality Summary**

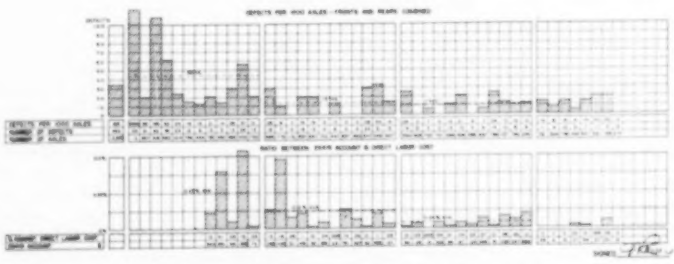


Figure 10—**Customer "D" Quality Summary**

Right foreground: a system which automatically controls electrical resistance of the electroplated wire. *Left foreground:* a system which automatically moves, at a predetermined time interval, from wire to wire, measures and records the resistance of each.

New Example of Quality Control

Here you see QC at work in one of the giant new electroforming machines developed by engineers at Western Electric. In these machines 25 strands of steel wire travel in parallel 850 feet from supply spool to take-up reel. In tanks along the way, copper, lead and brass are deposited electrolytically in tandem.

For this type of product, where electrical resistance is a major consideration, effective control is necessary from an economic standpoint. Our prime objective is to apply the necessary amount of copper and no excess. To do this it was necessary to provide control over such variables as:

1. Incoming electrical line voltage fluctuations.

2. Possible failure of one of 16 rectifiers feeding the copper plating section.

3. Changes in activity of the electrolyte due to temperature or concentration variations.

4. Changes in distance between anode bed and wire due to continuous consumption of anode during plating.

5. Wire speed changes.

6. Operation of machine at less than capacity number of 25 channels.

Automatic regulation of the amount of copper on the wires in the machine originates with a measurement of the electrical resistance of one of the wires selected as a pilot for the remainder. Electrical intelligence from this continuous measurement is translated into an adjustment, when required, of the total value of the plating current upon which the amount of copper deposited is directly dependent.

In addition, each machine has an automatic inspection device which measures the resistance of each of the 25 wires and records the values on a chart in order to provide a continuing picture of the effectiveness of the control systems.

Just one more example of how Western Electric engineers have long applied quality control to making good Bell telephone equipment at low cost.

Western Electric

A UNIT OF THE BELL SYSTEM SINCE 1882

Such quality improvement is extremely gratifying, and reflects the effort and push behind the quality program at Timken-Detroit Axle.

Figure 12 shows the over-all quality picture for all customers. During 1949 an expenditure equivalent to 10.9 percent of the direct labor costs was required to correct lack of quality. During 1951, through August, this expenditure dropped to 3.3 percent of direct labor costs. This is a reduction of 63.1 percent in this cost as compared to 1949 and certainly indicates improved quality.

All quality control operations center under the supervisor in the home office in Detroit, although there are quality control managers at the various plants. Actually, of course, virtually everybody is on the quality control team, from the president to the machine operator.

A keystone in our system is a report called "Request for Action." This originates with the quality control men or supervision and is a written report calling attention to some point in the manufacturing process where some maladjustment exists.

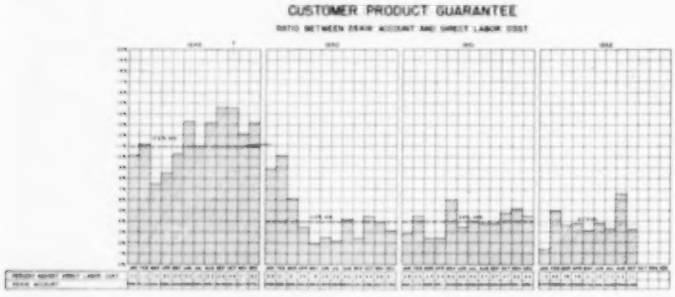


Figure 11—**Overall Quality Summary and Cost Ratio**

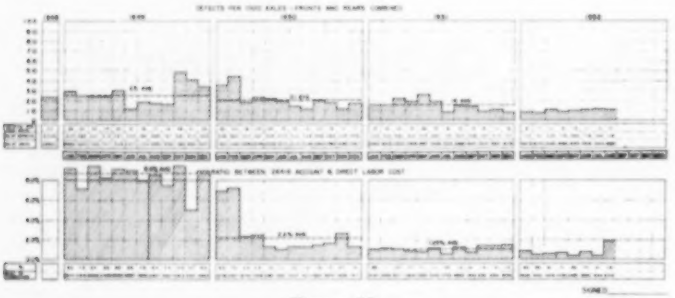


Figure 12

IT'S WHAT YOU DO ABOUT QUALITY THAT COUNTS

Achieving such results requires hard work and organization. As indicated before, the products of Timken-Detroit are varied and numerous. Another point to be considered is that much of our production is short-run, which means a large number of set-ups, changing of dies, adjusting of tools, etc. Hence the manpower requirements of our quality control force are greater than those of some other industries.

A typical "Request for Action" is addressed to the quality control investigators, to the plan manager, master mechanic, production foremen, and quality control people. It lists the plant, department, part, machine, and operation. It states the problem simply and winds up with "Please Investigate." This request is immediately referred by the plant manager to the departmental production foremen for action, and he must return a written reply on the back of the request, outlining the corrective steps he has taken.

To aid the production people, one of the 24 QC investigators in the nine plants studies the problem if necessary and recommends corrective action. To prevent any of these requests being lost in the shuffle, a running progress report is maintained. This report is up-dated every two weeks and contains the latest information on what is being done about each problem. New requests are added as received and old ones are not removed until satisfactory corrective action has been taken.

These progress reports also provide the agenda for weekly quality control meetings at each of the nine plants. Out of these meetings, too, comes the editorial material for the *Quality Controller*. This publication, launched last year, is devoted to the presentation of quality control problems and their solutions. It is prepared by the division and is written for the employe in simple, non-technical language. However, it is already proving to have a broader appeal. As the result of requests, we are now also sending copies to customers and other industries which have expressed an interest.

This, then, is the quality control system at Timken-Detroit. It works, and the five-year record proves it.

October 30, 1950.

Messrs. Grayson, J. Bush, E. Bray, L.
St. Clair, W. Hockey, D.
Sheppard Bradley, Wm.
Dawson, H. Senior, W.
Wells, J. Degeorge, T.

CC Messrs. Gruning Bayer, Sr.
Osborn Waldorf
Keller Mayer, J.
Keller Bayer, J.
Johnson, F. E. Cook, W.

Quality Control Department Request for Immediate Action
(By Mr. W. Cook).

Dept. - 51
Part -6[illegible]-1-095 - 3035-E-211 Carriers
Mach. - 51-3023 Bullards Chuck - Tool P5L801
Oper. - Facing flange thickness, machining cup and sleeve bore, and turning tenon fit to size.

"This machine is producing scrap, due to jaws being loose on chuck causing carrier to be machined off center out on an angle leaving a thin wall at sleeve bore."

Will you please investigate

Foreman Dept. 51.

What action have you taken?

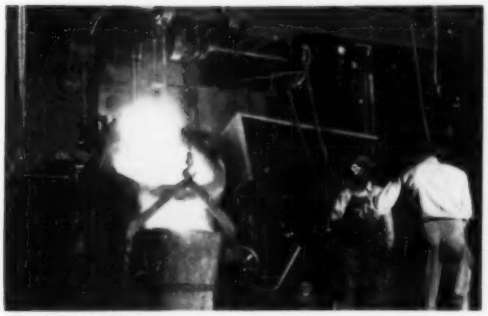
W. D. St. Clair

Figure 13—**A Typical Request for Action**

Through Integrated Production Operations

Willys-Overland Controls Quality

From Materials to Finished Products



FOUNDRY—All of the blocks used for Willys-Overland engines are cast in its foundry at Pontiac, Michigan.

FORGE—Willys-Overland produces forgings to the highest standards of quality control in its forge shop.

BODY PLANT—Statistical methods of physical inspection assure uniformly high quality of each unit.

ENGINE PLANT—Here is some of the precision equipment used in the Willys-Overland engine plant.

As a pioneer of statistical quality control, Willys-Overland uses advanced scientific methods recognized throughout industry. With its integrated production operations, such as those shown above, Willys-Overland carefully controls quality at every stage of manufacture, from materials to finished products.

As a leading manufacturer of military vehicles, Willys-Overland meets exacting standards required by the Government—standards which Willys-Overland also meets in its civilian production.

WILLYS-OVERLAND MOTORS

TOLEDO 1, OHIO

MAKERS OF AMERICA'S MOST USEFUL VEHICLES

"OPERATION EARTHMOVING" — another tough job that demands AMERICAN BOSCH performance

Dams, airports, super-highways . . . when contractors set out to move dirt, they really give Mother Earth a face lifting. And when projects involve millions of cubic yards of earth, giant trucks and earthmovers shoulder heavy loads . . . help meet tight schedules.

American Bosch products contribute to the dependable, economical, efficient performance of both Diesel and gasoline powered equipment. On Diesels, American Bosch supplies one of the most vital elements for reliable operation—the fuel injection system. And American Bosch electrical equipment—heavy duty generators, voltage regulators and magnetos—has long been a symbol of dependability in construction, as well as many other fields.

Today's American Bosch fuel injection equipment is the result of nearly two million man-hours of research and engineering. Combined with rigid standards of precision manufacture and skilled service, such thorough developmental work indicates why American Bosch products are held in such high regard in the automotive, aviation and Diesel fields. American Bosch Corporation, Springfield 7, Massachusetts.

AMERICAN BOSCH

The Statistical Approach to Bulk Sampling Problems*

B. H. LLOYD

Canadian Industries, Ltd.

POSSIBLY one should attempt at the outset of an article which appears under a rather nebulous title, to outline briefly his method of attack, because, if this does nothing else, it might save enthusiastic readers from proceeding further and suffering disappointment. There are many optimists eagerly pursing this panacea of bulk sampling problems up the trail of hope. There are others, and we can speak only of optimists, who diligently absorb what fragments of useful information they can glean from any piece of literature that they can find on the subject. This article is for those who are not too easily disappointed.

We should all have learned by now from close association with our mathematical colleagues, those of us who are fortunate to have them, that the only completely satisfactory approach to problems, which incorporate tangible variables, is that which is based on a plan or model. This does not mean that we try to fit the problem to the model, a common enough practice, but rather that we search for a suitable mathematical model which we hope can duplicate the behavior of the variables at least reasonably well.

It is unfortunate that there is not available at this time a general solution to all bulk sampling problems and it is very doubtful that there ever will be. There have been, however, some very commendable attempts to define the problems, [1,2] and noteworthy approaches to specific kinds of problems have been made. [3,4,5] This article is an attempt to contribute a little more thought on one specific classification of bulk sampling problems. The classification of which we speak here is that dealing with bulk materials consisting essentially of particles produced in a chemical process that are supposed to have the same ultimate composition. The problem attached to this classification is threefold

(i) the determination of the quantity of a sample unit,

(ii) the number of sample units for a given precision of quality estimate, and

(iii) the investigation of the causes of variation.

In the example discussed throughout, the first two considerations are not emphasized as much as the third, because of the limited scope of this article and the relative importance of the analysis of variance in studies of this nature.

In the manufacture of mineral fertilizers apatite is one of the commonest sources of phosphate. Apatite in its native form is not soluble as plant food and although ground apatite placed on the land is made available to plants through chemical action with humic acid and carbon dioxide in the soil, the conversion is a slow process. This is overcome by intimate mixing of ground apatite or phosphate rock with sulphuric acid which converts most of the insoluble tricalcium phosphate into the citrate soluble phosphate of superphosphate available to the plants. The fresh superphosphate produced in this way is stored in a large pile until the chemical reaction has virtually reached completion. The extent of the availability of the soluble phosphate determines the quality of the superphosphate and its commercial value. The flow diagram, Fig. 1, shows the various stages in the processing of superphosphate using the Ober method of manufacture. It might be remarked here, for those who are not familiar with the methods of superphosphate manufacture, that the Ober process is entirely enclosed. Phosphate rock dust and acid pass through a mixing valve to an autoclave where the pressure and heat of reaction help to bring about conversion and produce a product dry enough to be discharged without unreasonable delay. Depending on the degree of dryness of the discharge, the superphosphate may consist of large putty-like lumps or fine grain like free flowing particles. This latter consistency, known as pebble superphosphate, is preferable from the standpoint of both producer and consumer and commands a higher price. In storage, the superphosphate is allowed to cure for several weeks, which in effect brings the percentage of available phosphate to the high quality level required for compound fertilizers. Batches of superphosphate are not kept separate in storage, but it is possible to approximate fairly closely the elapsed curing interval for a particular day's production by noting the location in

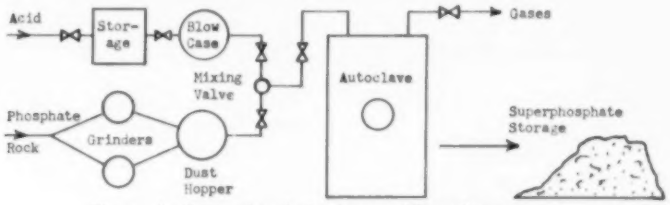


Figure 1—**Superphosphate Process Flow Diagram**

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the storage shed since a systematic method of piling is used.

Disposal of the cured superphosphate is divided between the producer who uses it in the manufacture of his own grades of compound fertilizer and the consumers who are compound fertilizer manufacturers themselves. Theoretically, to provide consumers with a quality estimate of their own shipment, it is necessary to assess the quality of each shipment. This practice is costly and through various studies an attempt is being made to provide a less costly and equally serviceable system of quality assessment.

The importance of selecting a system which will give a high precision to the quality estimate cannot be overstressed as the price of shipments depends entirely on the quoted value of the available phosphate and customers are sensitive to invoices which appear to overestimate the quality of the shipment.

The limitations encountered in sampling problems which fall into this classification are aptly summarized by Deming.[19] Selection of samples cannot be made independent of the human element because the material is not divisible into identifiable units; and bias, deliberate or unconscious, occurs quite frequently when selection is left to the human being. One could academically envisage the pile to be contained entirely in a great number of quart sealers which have been filled as the material enters storage and segregated according to batch and day. The human error in sampling shipments could be practically eliminated under these circumstances and a satisfactory system of quality assessment attained. This idea can be approached in practice where a conveyor belt is used for loading, and where the belt is not excessively long. Although the sample units are not identifiable in the strict sense, strips can be marked off across the width of the belt and numbered. Using a table of random numbers, the strips to be sampled can be designated prior to loading and the material constituting the sample unit scooped off if the belt is running slowly enough.

Another system virtually independent of the speed of the belt involves dividing the loading time into a number of equal intervals and selecting the sample on a random basis. At the appointed time, a container placed at the end of the belt removes a cross section which forms one unit of the sample. The quantity of material removed in one unit generally depends on the size and quality of particles of the material. In sampling mineral ore, for example, one large lump could seriously misrepresent the lot if the sample unit were not relatively large. Superphosphate is passed through about a nine-mesh screen before loading, a large percentage of the material having the consistency of sand. A cross section of the loading belt has a concentration of fine material in the center with coarser material on the outside uniformly distributed along the length of the belt, which significantly reduces the probability of particle bias. The laboratory sample is selected as a representative portion of the sample unit after it has been ground and thoroughly mixed.

In sampling superphosphate, the sample unit used at present is large enough to suppress the effect of particle bias and small enough to be easily handled.

The frequency of sampling selected to satisfy a given precision of quality estimate is subject to more capricious effects than the selection of the size of the sample unit. Since the quality estimate here can be permitted only a small deviation from the true quality, cost is not altogether the determining factor in choosing the sample size (the number of sample units in a sample). The variation among sample units within a shipment is the guide to the sample size. It should be mentioned that this is not the case in sampling compound fertilizers where both the amount of variation and the within-shipment pattern must be examined. In shipments of bulk superphosphate, the variation is inclined to be large but there is no indication of a non-random pattern at the point of loading over fairly short periods of time. The crux of the whole question of sampling here is what is happening to the variance, but before we can speak of the variance, we must have a definable universe. The universe envisaged here is the cured superphosphate shipped over a given period of time. If the period of time is long, the universe can and does continually change, in position and spread, under the influence of many effects.

It could be demonstrated in this article, if space permitted, that effects exist in the manufacturing process which appear as significant factors today, but tomorrow lapse into the shadow of random error, to appear again apparently voluntarily sometime in the future. If there are many of these unpredictable flyers in the process, the variance is unstable and the problem of standardizing a sampling scheme is extremely difficult. If the unpredictable effects are few, it is at least possible to obtain, with reasonable precision, some idea of the behavior of the variance.

Possibly the first and most important step towards the development of a satisfactory sampling scheme is to obtain control of the universe variance. In a reasonably well controlled continuous process, the universe selected for sampling may be quite large, but where possible, the universe should be selected to contain a system of effects which may be considered random for all intents and purposes. For example, superphosphate is normally allowed a six-weeks' cure, but when inventory runs low, it is sometimes necessary to use five-week super. If insufficient care is taken, the change takes place during the sampling of the shipment. Here an effect will have

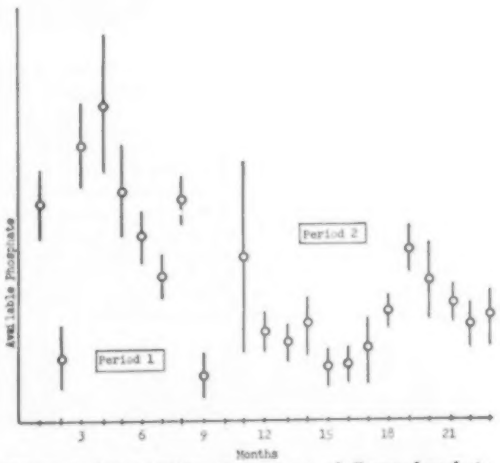

Figure 2—**Lot Quality Assessment of Superphosphate Showing Confidence Ranges**

been introduced which has virtually produced a new universe. The size of the universe should be such that the system of effects, even though not entirely random, should at least not be changed deliberately within the universe. A continuous unavoidable change in available phosphate would, of course, make this impossible, but under such circumstances, particularly where the change is sharp and takes place over a relatively short period of time, the size of universe sampled should be the size of the smallest shipment.

Fig. 2 shows two periods, the first a period of instability, the second a period of relative control. The vertical lines represent confidence ranges. It is readily apparent that some quality estimates of the first period are not as precise as those in the second. In this case, the lots which have been poorly assessed have been too large and have included effects which properly should have appeared in another lot. In quality control language, these lots are not rational subgroups.

Occurrence of periods such as those exhibited in the first period of Fig. 2 are not infrequent and have led to a number of process studies. Sampling of the lots may possibly have been made without careful consideration of proper proportions of large and small particles in samples. This could have been a factor in the variation among sample units. In addition, inconsistent operational factors among batches of superphosphate might have contributed to the apparent instability within and among lots.

One statistical experiment carried out on the superphosphate[2] manufacturing process to answer such questions is described here.[10] The experiment was designed to examine the relative contribution to variance of the effects of operational inconsistencies from batch to batch; between particle size groups, viz., fine and coarse; sampling error within batches and analytical error. The quality characteristic chosen for examination was, for chemical reasons, not the available phosphate, but some related characteristic which we will designate by the letter A.

TABLE I—**Analysis of Variance Breakdown**

Description of Effect	Degrees of Freedom	Mean Square Estimate
Among Batches	n_1-1	$n_2n_3n_4\sigma'^2_1+n_3n_4\sigma'^2_{12}+n_4\sigma'^2_3+\sigma'^2_4$
Between Size Groups	n_2-1	$n_1n_3n_4\sigma'^2_2+n_3n_4\sigma'^2_{12}+n_4\sigma'^2_3+\sigma'^2_4$
Batch x Size Group Interaction	$(n_1-1)(n_2-1)$	$n_3n_4\sigma'^2_{12}+n_4\sigma'^2_3+\sigma'^2_4$
Sampling Error	$n_1n_2(n_3-1)$	$n_4\sigma'^2_3+\sigma'^2_4$
Analytical Error	$n_1n_2n_3(n_4-1)$	σ'^2_4

TABLE II—**Coded Values of A**

Batch	Size Group							
	Fine				Coarse			
1	95 73	92 69	113 100	60 59	20 26	95 104	96 96	68 71
2	142 129	131 105	71 82	88 109	150 148	160 166	60 60	111 88
3	81 117	109 112	138 91	105 107	111 111	114 121	150 102	155 132
4	106 100	39 —2	89 101	114 113	105 82	67 85	192 137	140 168
5	129 125	108 68	79 38	89 113	142 128	98 118	141 113	99 113
6	39 102	119 128	39 23	38 71	122 145	16 73	—29 —30	79 77
7	88 102	65 70	107 109	93 95	36 29	69 70	161 109	140 135
8	100 100	92 108	169 153	136 130	131 133	54 82	138 171	154 170
9	67 68	87 91	87 88	87 104	36 50	135 54	102 70	137 130

The simple linear mathematical model chosen is expressed as:

$$X_{ijkm} = \mu + \alpha'_i + \beta'_j + \gamma_{ij} + \varepsilon_{ijk} + \lambda_{ijkm}$$

where X_{ijkm} is the m^{th} replicate observation of the k^{th} sample unit of the j^{th} size group of the i^{th} batch and where

α'_i is the batch to batch effect

β'_j is the size group effect

γ_{ij} is the normally distributed batch x size group interaction effect

ε_{ijk} is the normally distributed effect among sample units due to within-batch heterogeneity

λ_{ijkm} is the normally distributed effect of analytical inconsistencies

All of these quantities are distributed independently of each other and have zero means.

TABLE III—**Analysis of Variance**

Description of Effect	Degrees of Freedom	Sum of Squares	Mean Square Estimate
Among Batches	8	48002	6000.25
Between Size Groups	1	2934	2934.
Batch x Size Group Interaction	8	9716	1214.50
Sampling Error	54	136709	2531.65
Analytical Error	72	21931	304.59
Total	143		

Let the variance components be

$V(\alpha_i) = \sigma'^2_1$ estimated by s_1^2

$V(\beta'_j) = \sigma'^2_2$ estimated by s_2^2

$V(\gamma_{ij}) = \sigma_{12}^2$ estimated by s_{12}^2

$V(\varepsilon'_{ijk}) = \sigma'^2_3$ estimated by s_3^2

$V(\lambda'_{ijkm}) = \sigma'^2_4$ estimated by s^2_4

$n_1 = 9$ = number of batches

$n_2 = 2$ = number of size groups

$n_3 = 4$ = number of sample units per size group per batch

$n_4 = 2$ = number of replicates

The general analysis of variance breakdown is given in Table I. Table II shows the data for the problem under consideration and Table III is the analysis of variance for this problem.

Testing the effects in Table III for signifiance at the 95 percent level using the F ratio, we have

Among Batches

$$F = \frac{6000.25}{2531.65} = 2.37$$

$F_{.05} = 2.11$ for 8 and 54 d.f.

Between Size Groups

$$F = \frac{2934}{2531.65} = 1.16$$

$F_{.05} = 4.02$ for 1 and 54 d.f.

Interaction

$$F = \frac{2531.65}{1214.50} = 2.08$$

$F_{.05} = 3.03$ for 54 and 8 d.f.

Note that the F ratio for the interaction effect, shows a significantly small effect since the batch x size group interaction mean square is less than the sampling error mean square.

For the among-batch effect we draw the inference that $\sigma'_1{}^2$ is not zero. However, it appears that the between-size group effect and the batch x size-group interaction effect have zero variances, that is $\sigma'_2{}^2$ and $\sigma'_{12}{}^2 = 0$.

Working out the variance component estimates

$$s_1{}^2 = 217$$
$$s_3{}^2 = 1114$$
$$s_4{}^2 = 304$$

It would seem from these results then, that if we were to perform single analyses on sample units taken at random from the superphosphate process irrespective of batches or size groups, that by far the greatest source of error among the observations should be attributed to heterogeneity within the batches. As a matter of interest, it was suspected prior to the experiment, that the greatest source of error would occur among batches and that the between-size group effect would have a relatively large variance.

From a purely technical standpoint there is quite good reason to suspect heterogeneity within batches because intimate mixing of the phosphate rock dust and the acid, which are forced under pressure into the autoclave, is not a simple achievement, particularly since the control valves are opened and closed by the operators. The result of this experiment carried enough strength to justify a research project on primary mixing of acid and rock dust.

An inspection of the analysis of variance tables might give rise to some wonder at the relative sizes of the batch x size-group interaction and the sampling error mean square. Whether or not a fair degree of batch bias was expected to influence the size groups, it appears that the sampling error is larger than the interaction effect although not significantly so. There is every indication that an additional experiment should be carried out.

The fact, however, that the particular mathematical model chosen to fit this experiment may not have been appropriate in all aspects, is something which must not be overlooked. For example, it cannot be rigidly assumed that sample units are independent of one another, since acid in excess at one spot in the autoclave must mean a deficiency of acid in another, and each sample unit of phosphate rock has not had an equal chance of exposure to its allotment of acid. This virtually means that the sample units are correlated, which would account for a large within-batch variation and provide an invalid basis for assessing the batch and size group effects.

Statistical experiments such as the one just described might seem by some to be a little out of line with problems of bulk material sampling, but possibly not when it is considered that sampling depends so largely on the behavior of the variance. For example if we take the above experiment at its face value, the variance of the cured superphosphate could attribute much of its size to inadequate mixing of phosphate rock and acid in the autoclave and not to the inconsistency of operation occurring among batches. Were it possible to retain the identity of the batches during the curing period, estimates of components of variance within and among batches would be necessary in selecting the number of batches to be sampled and the number of sample units per batch. A course such as this is followed in the U.S. Customs.[5] In addition it might be pointed out that although superphosphate particles of various size classes do not appear to be correlated with quality, DeLury [6] has offered a method of sampling material where quality trends are exhibited, for example across a conveyor belt where the higher density particles seek the lower levels of the strip and a pattern is effected.

For normal superphosphate shipping periods the variance among sample units taken at random over a period of about a week appear to reflect about the same variance as that estimated over a much smaller period, say an hour or so. In other words conditions do not voluntarily change appreciably over a period of a week's time. Changes which do appear, apart from occasional inexplicable irregularities, are gradual trends in raw material quality and more frequently understandable the crane operator in the storage warehouse.
misjudgment of the degree of cure of superphosphate by

On the basis of assessing the quality of collective shipments over the period of a week which is virtually stable it follows that the weekly average gives as precise an estimate of any portion of the weekly shipments as would the average of the same number of sample units from that portion. This obviates the necessity of assessing each shipment individually. Early practices favored compositing sample units for the period over which the quality assessment was desired but this has been modified for obvious reasons—one being that no running check is available on the variance.

In all sampling schemes we must tolerate a risk which is the probability that the true average quality of the material sampled does not lie within a fixed range about the sample mean. [10] In quality control circles this is known as the consumer's risk. For example, sampling specifications might read "The number of sample units must be such that the true average quality of shipments made during the week shall lie within ± 0.05 percent available phosphate about the sample mean with the concession that only five out of 100 times may these limits be violated." In statistical language these limits are known as 95 percent confidence limits.

Let us assume that repeated sampling of weekly shipments of superphosphate give analyses of available phosphate which are more or less normally distributed, with a standard deviation of 0.187. How many sample units should be taken per week to assure with 95 percent confidence that the true average quality of a week's shipments lies within the limits of ± 0.05 about the sample mean.

Using normal distribution theory we have

$$N = \left(\frac{k'}{0.05}\right)^2 = \left(\frac{1.96 \times 0.187}{0.05}\right)^2 = 54$$

This same result can be arrived at using Tanner and Deming's formula[10]

$$N = \frac{(tV_s)^2}{E}$$

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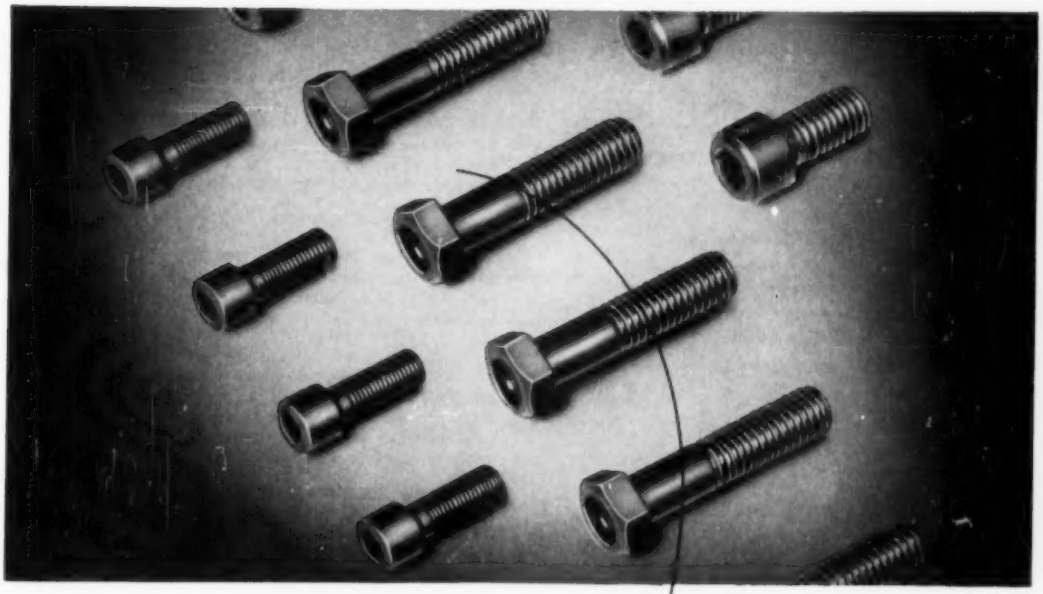

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where t is equivalent to k above = 1.96, V_s is the coefficient of variation = 1 percent, and E is the allowable uncertainty of the sample mean = 0.0025. Then

$$N = \left[\frac{(1.96)\quad(0.187/20)}{(0.05/20\ )}\right]^2 = 54$$

It matters very little what formula is selected as long as the essential basic concepts are taken into consideration.

Assuming that 54 samples are necessary to give the required precision of quality estimate, it was suggested earlier that a modified form of compositing might be used to cut down on analyses and still provide an estimate of the sampling variance. If the laboratory error, which consists of both analytical and laboratory sample-preparation error, is $\sigma'^2_s = 0.005$, what is the most economical number of composite samples and replicate analyses in keeping with the desired precision of the quality estimate?

$$\sigma'^2 = \sigma'^2_s + \sigma'^2_a$$

$$\sigma'^2_{\bar{X}} = \frac{1}{m}\left(\frac{\sigma'^2_s}{n} + \frac{\sigma'^2_a}{r}\right)$$

Where $\sigma'^2_{\bar{X}}$ is the variance of the average of composite samples

σ'^2 = universe variance
σ'^2_s = sampling error variance
σ'^2_a = laboratory error variance
m = number of composite samples
n = number of sample units per composite
r = number of replicates per composite

Given σ'^2_s=0.030 and σ'^2_a=0.005, values of m, n and r must be selected to comply with $1.96\,\sigma_{\bar{X}}' \leq 0.05$ or $\sigma'^2_{\bar{X}} \leq 0.000651$

It follows that

$$\frac{1}{m}\left(\frac{\sigma'^2_s}{n} + \frac{\sigma'^2_a}{r}\right) \leq 0.000651$$

The minimum number of sample units necessary has been found to be 54, but it is obvious that irrespective of how we break this down into composites the total number of analyses must be 54 to meet the precision requirements.

For example if we divide the 54 sample units into, say six composites of nine sample units each, although only six samples are submitted for analysis nine replicate analyses must be obtained for each sample in order to comply with precision requirements. If we are limited to 54 sample units, the most economical scheme is one analysis for each of the 54 samples.

With no limit on the number of sample units the most economical combination of m, n and r depends entirely on the cost of sampling and analyzing. A somewhat similar problem is discussed by Brownlee [7] who has computed a table of the optimum number of analyses per sample for given values of σ'^2_s/σ'^2_a and the ratio of cost of sampling to cost of analysis. By "optimum number" he has in mind the number of replicates to give the minimum variance for any total expenditure where a linear relation exists between the cost of analysis and cost of sampling.

An additional variable, m, is added in this problem and a non-linear relation exists between costs, Figs. 3 and 4, but the general solution to this can be found easily

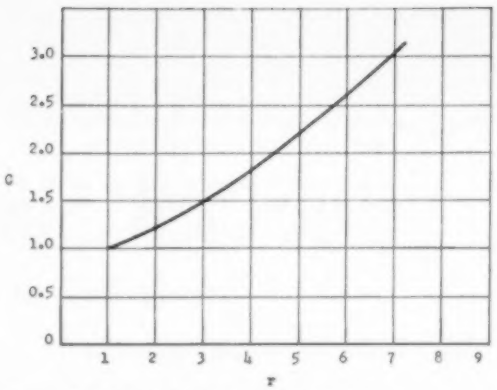

Figure 3—**Cost of Replicates Per Sample**

with knowledge of the equations of the cost curves. Fig. 4 gives the cost of preparing a composite for a given number of sample units. Fig. 3 gives the cost of replicates per composite sample.

The cost of preparing and analyzing a composite must be multiplied by the number of composites to give the total cost. Table IV gives total costs for various values of m, n and r. For a given value of r there are values of m and n which give a minimum cost for the set but when r = 4, m = 4, n = 22, the total cost is a minimum.

It is seen, therefore, that four composites of 22 sample units, each with four replicate analyses, is the most economical plan for the required precision. The total number of sample units necessary is 88, and 16 analyses must be made in all.

Finally we make some provision for checking the sampling error variance from week to week. This can be done in a number of ways the simplest of which is perhaps by plotting the sampling error standard deviation of composite averages on a quality control chart. From $\sigma_s' = 0.173$ the 2σ limits for $\sigma_s/\sqrt{n}$ are [8]

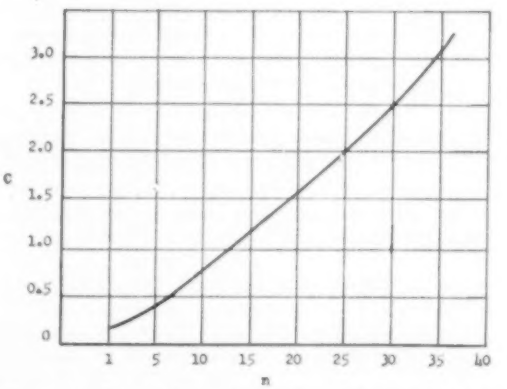

Figure 4—**Cost of Preparing a Composite Sample of n Sample Units**

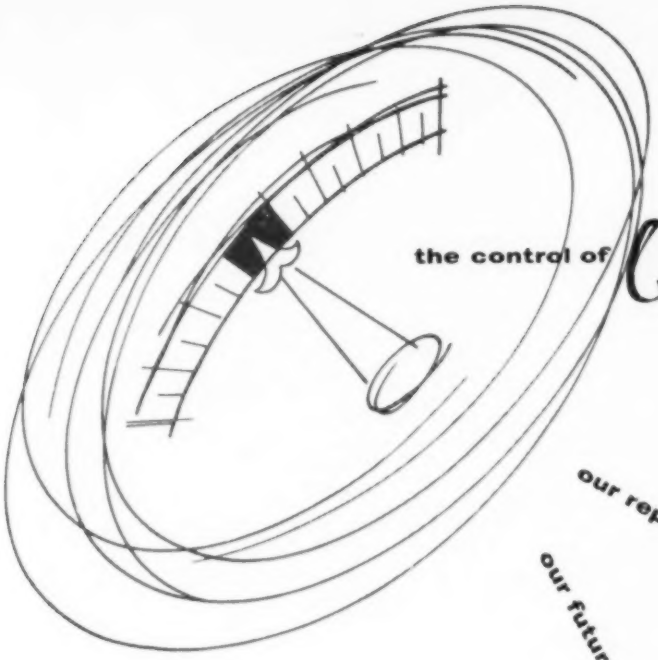

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TABLE IV—**Total Cost of Composite Sampling and Analysis**

$\sigma_s'^2 = 0.03$, $\sigma_r'^2 = 0.005$. Precision of $\bar{X} = \pm 0.05$

Equation: $m = \frac{46.1}{n} + \frac{7.68}{r}$

r	m (rounded)	n	C
1	13	10	23.2
	12	11	22.3
	12	12	23.3
2	6	20	18.6
	6	21	17.3
	6	22	17.7
3	7	13	17.2
	6	14	15.3
	6	15	15.8
4	5	21	17.2
	4	22	14.0
	4	23	14.4
5	4	30	18.7
	3	31	14.4
	3	32	14.8

upper limit = 0.046

lower limit = 0.026

central line = 0.036

where n = 22 and $c_2 = 0.966$.

Plotting values of $\sigma_s/\sqrt{22}$ on this chart we are taking about a 5 percent risk of revaluating σ_s' when in actual fact σ_s' has not changed, if the process is stable.

These thoughts put into practice have provided a fairly satisfactory sampling system for bulk superphosphate. Although many of the details are applicable only to this process it is not the details about which we should be concerned when examining a specific case but the ideas themselves. The details should be arrived at through common sense. What we wish to have is a stable variance of unassignable random causes within the universe to be sampled. If effects are present apart from this so-called error, then they must be controlled in such a way that their contributions to variance are measurable. It is for this task that we have the mathematical model and the statistical technique.

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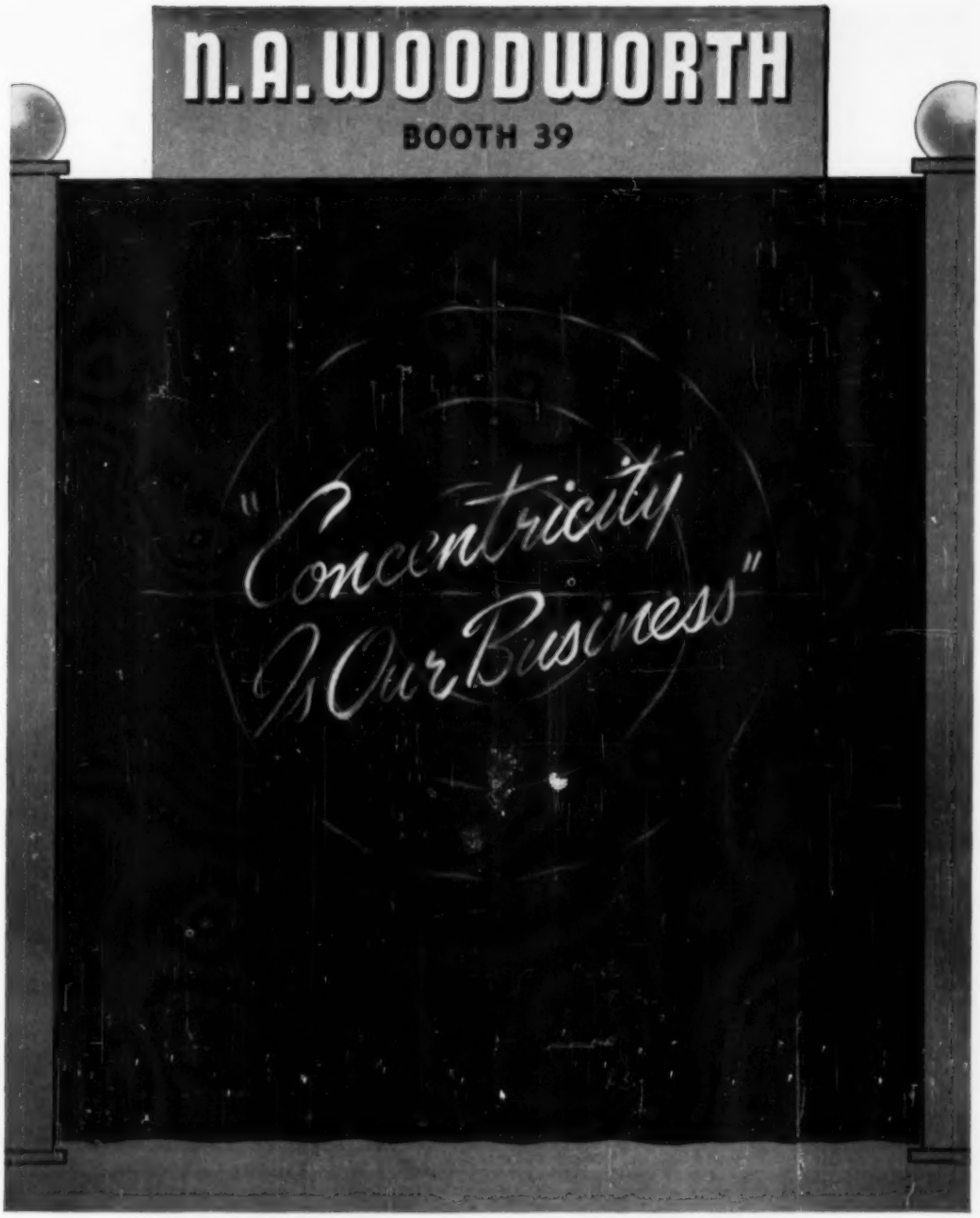

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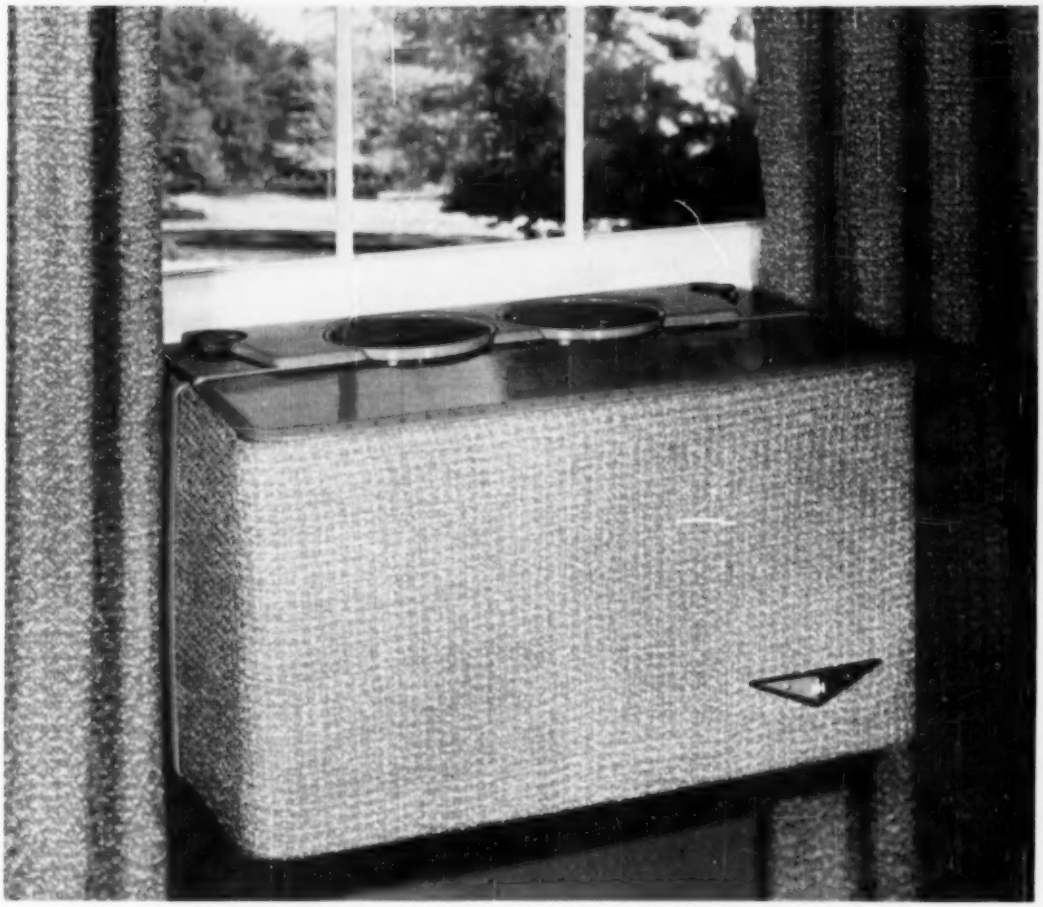

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A Production Experiment with Mechanical Assemblies

ELLIS R. OTT
Rutgers University

1. Introduction. During the production of an electric kitchen-mixer, a company was finding some rejects at final inspection for "inefficiency." Different production experiments had been run to determine causes of defective units, but little improvement had been effected over several months of experimentation. It was agreed that new methods of experimentation should be tried.

2. Choice of factors to include in the experiment. There were different "theories" advanced to explain the trouble; each theory had some evidence to support it and some to contradict it. A small committee representing production, engineering, and quality control met to discuss possible reasons for the trouble.

One gear-assembly (henceforth called "gears") was definitely suspect; it connected the top half and bottom half of the mixer. But there was no assurance that gears were the only source of trouble. A program to inspect gears for "out-of-round" and to use only the "best" was in process of formulation.

Then this question was asked: "If it isn't the gears, is the trouble in the top half or the bottom half of the mixer?" There was no answer to the question. Since each half is a complicated assembly in itself, it was agreed that it would be important to isolate the trouble in one-half of the mixer rather than just look for trouble "someplace." With this agreement, there were now three "natural" factors to include in the experiment—factors which had been developed in committee discussion. The three factors were simply:

Tops	(T)
Bottoms	(B)
Gears	(G)

The trouble must certainly be caused either by one or more of these separate factors directly (main effects), or perhaps by the interdependence of two of these factors (interaction). Evidently further experiments might be required after the results of this preliminary experiment were available.

3. Arrangement of the factors in the experiment. Our interest in this experiment was to determine why some of the mixers were "Inefficient," or why some of them were "Efficient." It is important to note that there was no equipment available at the plant to measure the "degree of efficiency" of a mixer, but only that it was "Efficient," (E), or "Inefficient," (I); data were of the go no-go variety.

It was agreed, then, to select a "reasonable" number $4n = 24$ (see Note 1) of E-mixers and an equal number of I-mixers. Then each mixer was to be disassembled and a mark placed on each component (Top, Bottom, and Gear) which came from the I-mixers; the E-components were left unmarked. (We must remember that those components designated either E or I were so designated on the basis of the mixer-rating of which it was originally a component. The purpose of the experiment was to establish which components or combinations of them actually were E or I components.)

A reassembly (see Note 4) of components from the three different groups was scheduled according to the design of Figure 1 (see Note 2). For example, Group 2 indicates the reassembly of mixers from six sets each of E-gears, I-tops, and E-bottoms. Then after reassembly (with parts selected at random), each "new" mixer-reassembly was rated by the original inspector as either E or I. In case of doubt, a rating of "½" was arbitrarily assigned. The number of I-mixers of each of the eight groupings found after reassembly is shown in Fig. 2. There were 48 mixers reassembled from the parts, and the total number of I-mixers attributed to the components (as main effects) was as follows:*

G_I (1,3,5,7): 14	T_E (3,4,7,8): 8½
G_E (2,4,6,8): 15½	B_I (1,4,6,7): 14½
T_I (1,2,5,6): 21	B_E (2,3,5,8): 15

*The total number of I-mixers attributed to I-gears, for example, is the total within the groups 1, 3, 5, and 7.

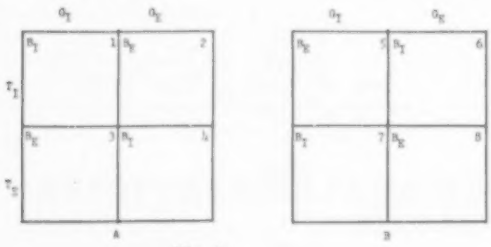

Fig. 1

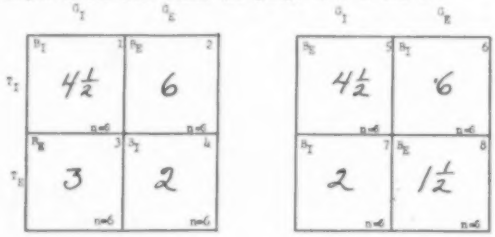

Fig. 2

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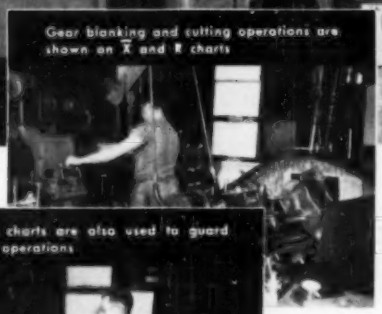

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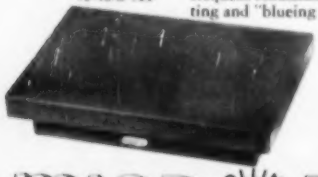

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4. Analysis. If gears were the cause of trouble (as predicted), then the mixers reassembled from the I-gears should rate I, and mixers reassembled from the E-gears should rate E. But if the trouble came not from gears alone but from the way in which gears were paired with tops, then this could be expected to appear as a gear-top interaction.

Now if the effect of any factor in this experiment is significant, it is evidently the effect of the tops.

These data have been represented graphically in Fig. 3. Dotted lines have been drawn (see Note 3); the distance between them has been represented by the symbol $2\sigma_{\bar{x}}$. Points which fall within these lines cannot be considered to correspond to important explanations of the causes of I-mixers (at the 95-percent confidence level)—thus we conclude that neither gears nor bottoms, as such, are important sources of the trouble.

The point corresponding to the I-tops falls above the dotted line. Our interpretation, then, is that the tops which came from the I-mixers are actually causing trouble.

Can we say, then, that gears have no effect? If we look at the interaction analysis in Fig. 3, we see that the most suspicious effect is the gear-top relationship. Certain gear-top combinations may be suspected at roughly the 90-percent confidence level but not at the 95-percent level. It appears that the most important effect to study is that of the tops, and experiments should be designed to localize the source of trouble within the tops. (This was done subsequently by dividing the top into three areas and making reassemblies in a manner similar to that used in this experiment.) The major source of trouble was isolated and the nature of corrective action on component parts was indicated.

Note 1: The choice of 24 I-mixers and 24 E-mixers was dictated primarily on the basis of expediency. With this number of mixers, it was estimated that the reassembling and testing could be completed with the remaining two hours of the work-day. This was an important factor because some members of the committee were leaving town the next morning and it was important to have at least an indication of what would happen. Secondly, it was expected (at least by some) that the cause of the trouble would be immediately apparent with even fewer reassembled mixers than with 24 of each kind.

This type of experimentation with mechanical, or electrical-mechanical assemblies is a powerful means of localizing the source of trouble. This production

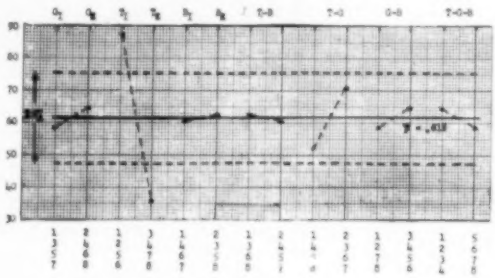
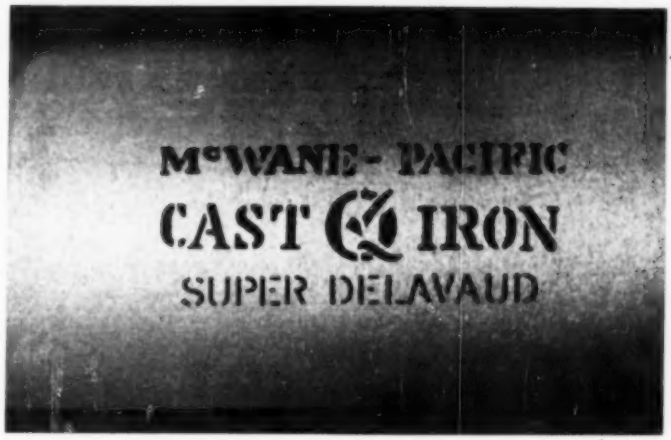


Fig. 3



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experiment was completed within a period of approximately two hours.

It should be noted that the "cure" of this "Inefficiency" trouble was not found. However, the previous decision to cure the trouble by inspection of "out-of-round" gears was shown to be futile, and the *area* of trouble was found. This enabled the group to run a similar experiment by dividing the top into three natural components, and the cause of trouble was found to be in the stator.

Note 2: There are several things to consider before deciding on the design of this experiment. If we include all eight combinations of these three factors then it is called a *Factorial Design*. If a certain four are used, either as in Fig. 1a or Fig. 1b, then it is called a *Latin Square*. In some cases, it would be hopelessly confusing to send all eight combinations through the production process or it might require more time than is permissible. If it is predicted that there may well be certain *pairings* of two of the factors (interactions) in the experiment which must be maintained, then we usually recommend the Factorial Design unless there are very good reasons against it. Sometimes we begin with a Latin Square, and then perform the other Latin Square which completes the Factorial Design if the results of the first one leave us in doubt.

Many writers have described experiments in which they include five, six and even more variables in an experiment. Such experimentation has its place in laboratory research or in a plant where a statistical analyst has established himself in the confidence of his production colleagues.

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But when introducing experimentation with two or more factors simultaneously, it is essential that *understandable conclusions* of the experimentation be presented. A graphical presentation is feasible with two and three variables—then by the time confidence has been established in the techniques of experimentation with several factors, it is time to consider the design of experiments with more than three factors. Nothing of value is accomplished if our experiment identifies factors which are important in our process but which fails to present convincing evidence to the men who direct the process.

Note 3: There are seven comparisons to be tested for significance. In each comparison we combine particular sets of four groups and compare them with the remaining four groups. The combinations, each of which includes a total of 4 x 6 = 24 mixers, have the following ratios of I-mixers:

Main effects

$G_1(1,3,5,7)$: $p_1 = 14/24 = .583$
$G_E(2,4,6,8)$: $p_2 = 15\frac{1}{2}/24 = .646$
$T_1(1,2,5,6)$: $p_3 = 21/24 = .875$
$T_E(3,4,7,8)$: $p_4 = 8\frac{1}{2}/24 = .354$
$B_1(1,4,6,7)$: $p_5 = 14\frac{1}{2}/24 = .604$
$B_E(2,3,5,8)$: $p_6 = 15/24 = .625$

First order interactions

T-B $(1,3,6,8)$: $p_7 = 15/24 = .625$
$(2,4,5,7)$: $p_8 = 14\frac{1}{2}/24 = .604$

G-T $(1,4,5,8)$: $p_9 = 12\frac{1}{2}/24 = .520$
$(2,3,6,7)$: $p_{10} = 17/24 = .708$

G-B $(1,2,7,8)$: $p_{11} = 14/24 = .583$
$(3,4,5,6)$: $p_{12} = 15\frac{1}{2}/24 = .646$

T-G-B $(1,2,3,4)$: $p_{13} = 15\frac{1}{2}/24 = .646$
$(5,6,7,8)$: $p_{14} = 14/24 = .583$

It is our problem to decide whether the percents p_i and p_j within each pairing are significantly different (corresponding to chosen significantly different). Now the total number of I-mixers found in the 48 reassemblies was $29\frac{1}{2}$, and

$$\bar{p} = 29\tfrac{1}{2}/48 = .615.$$

The average of any of the above seven pairs of percents, such as p_1 and p_2 is

$$\frac{p_1 + p_2}{2} = \bar{p} = .615$$

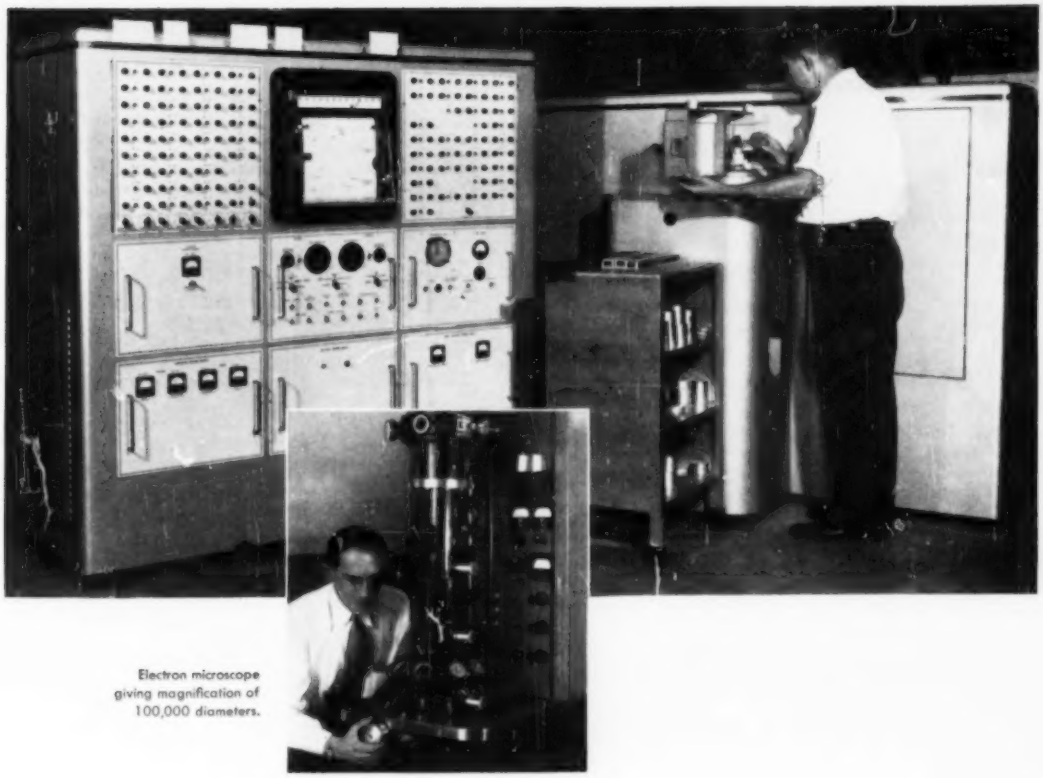
Geometrically, this means that each of the seven pairs of points is symmetrical to the line drawn at $\bar{p} = 0.615$ (see Fig. 3).

To test whether such a pair of these percents, such as p_i and p_j, where

$$\frac{p_i + p_j}{2} = \bar{p} = .615$$

could have (corresponding to chosen probabilities) come from a process with $p_\cdot = 0.615$, we compute the quotient,

$$q = \frac{p_i + p_j}{\sigma_\Delta}$$



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The symbol σ_Δ represents the "standard" deviation of the difference of two percentages. In our example, we are comparing samples of size n = 24 drawn from a process with $\bar{p} = 0.615$

$$\sigma_\Delta = \sqrt{2}\ \sigma_{\bar{p}}$$

where $$\sigma_{\bar{p}} = \sqrt{\bar{p}\,\frac{(1-\bar{p})}{4n}} = \sqrt{\frac{(.615)\ (.385)}{24}} = .099$$

Then $$\sigma_\Delta = \sqrt{2}\ \sigma_{\bar{p}} = \sqrt{2}\ (.099) = .140$$

A quotient of two would be exceeded, on the average, about *once in twenty* times (corresponding to 2σ or 95.4 percent assurance).

Now a geometrical representation of this test can be made by drawing lines (as in Fig. 3) at:

$$\bar{p} + \sigma_\Delta = .615 + .140 = .755$$

$$\bar{p} - \sigma_\Delta = .615 - .140 = .475$$

These two lines are a distance of $2\sigma_\Delta$ apart. When any pair of (symmetrical) percentages are drawn on the same graph with this pair of lines, they are seen to be significantly different (at the 2σ level) provided they *are outside* the two lines.

Similarly, lines can be drawn to represent a difference at the 3σ level (99.7 percent assurance) by drawing lines at a distance of $\frac{3}{2}\sigma_\Delta$ above and below the line corresponding to $\bar{p}$. These lines would be at 0.825 and 0.405.

Then in Fig. 3, we see that the only percentages which are significantly different (at the 2σ level) correspond to T_I and T_E. (This difference is also significant at the 3σ level.)

Note 4. In this experiment it was possible to select enough E-mixers and I-mixers (24 of each) to make all 48 reassemblies at the same time, and no component was used in more than one reassembly.

But if only six E-mixers and six I-mixers were available, the above experiment could still be performed. We would use the appropriate I-components and E-components to obtain six reassembled mixers for one of the eight groups, then dismantle the six mixers and be ready for another reassembly group. This can be continued until all eight groups of reassemblies are obtained. The same values of σ_Δ can be used to draw lines to test for significant differences as described in Note 3; however, the probabilities associated with σ_Δ will not correspond exactly to 95.4 percent assurance but will be changed slightly. Lines which are $2\sigma_\Delta$ apart to slightly less than this.

This method of reassembly of mechanical assemblies presents many opportunities both in production and in development work.

Problems Department

PAUL C. CLIFFORD, Editor

Problems for solution, and correspondence concerning material published in this department, should be addressed to
PAUL C. CLIFFORD
39 Norman Rd.
Montclair, N. J.

Back Home and Broke

Going to India on a United Nations Mission on Quality Control was in many ways a most rewarding experience. It was a challenge to try and find solutions for an entirely new set of problems. And believe me, India has problems too. We hope that we did not create more than we solved. We left with the firm belief that given time India will discover satisfactory solutions for her problems. And we returned to ours here with the feeling that they should be relatively easy.

Oh, We Ain't Got a Barrel of Money

This feeling was quickly dispelled as we faced good old Form 1040. Every time that we tried that one we kept hearing Mark Twain's crack about liars, damn liars and statisticians, and wondered if the Bureau of Internal Revenue really believed it. Then there was the arrival of Justin, the sixth little Clifford. Since he was just too late for an additional deduction, we couldn't see why he should not be called Justout. Wife wouldn't hear of it. And when we proudly remarked to a friend that we now had a basketball team of five boys with a girl manager, he squelched us with the answer that baseball was more popular.

Have You Forgotten So Soon

Somewhere in all this hubbub the problems department got lost. Not for lack of problems or suggested solutions. Just plain inefficiency on the part of the editor. With sincere apologies to those of you who sent in problems and solutions, I will now get back to work on the problems department. Here are a couple of new ones—on the problem of finding the control limits. Here is Mr. King's letter:

"In the September 1951 issue of IQC you pose the following demerit rating problem. A product is being inspected for four types of defects, where the weights assigned to the different types are—

Class A—Critical Defects, 100 demerits

Class B—Serious Defects, 50 demerits

Class C—Moderately Serious Defects, 10 demerits

Class D—Minor Defects, 1 demerit

In constructing a control chart for d_i, the total number of demerits for the i^{th} unit, how do we compute control limits?

"This question was answered by H. F. Dodge in a paper entitled, 'A Method of Rating Manufactured Product,' Bell Telephone Laboratories, Reprint B-315. The essentials are as follows:

"If we let (1) d_i be the total number of demerits for the i^{th} unit, (2) N be the total number of units, (3) n_{1i} be the number of Class A defects in the i^{th} unit (and so on up to n_{4i}), then

$$d_i = 100n_{1i} + 50n_{2i} + 10n_{3i} + n_{4i}$$

Control limits should be calculated as

$$U(L)CL = \bar{d} \pm 3s_d$$

where

$$\bar{d} = \frac{d_i}{N}$$

$$s_d = [(100)^2 n_1 + (50)^2 n_2 + (10)^2 n_3 + n_4]^{1/2}$$

the n's being the average number of defects of a particular type per unit, for example

$$n_1 = \frac{n_{II}}{N}$$

Problem 8

Submitted by T. Shahnazarian, Metropolitan Section

A single-sampling plan n = 50, c = 0 is used. If one defect is detected, inspection of the sample is terminated. A record of the sampling inspection may resemble the following:

No. Pieces Inspected	No. Defects	Disposition
50	0	Accept
50	0	Accept
6	1	Reject
39	1	Reject
50	0	Accept

How can one proceed to estimate the average fraction defective of the lots coming into inspection?

Problem 9

Submitted by Leonard Cassert, Metropolitan Section

We are using single-sampling plans, under conditions where the Poisson distribution is a satisfactory model. Is there any simple algebraic relationship between the n and c of a sampling plan and the AOQL? The fraction n/N in this case is seldom greater than 0.01.

Problem 10

Submitted by August B. Mundel, Metropolitan Section

The problem of how many control charts to maintain and for how long is a difficult management decision. However there are many applications where the control chart in general shows reasonable control, corrective action is seldom needed, and the arithmetic labor of maintaining a control chart appears to be an unnecessary burden. What control procedures can be used that will maintain point-by-point control and reduce the arithmetic work to a minimum?

Problem 1. Suggested Solution

We received comments on this problem from E. P. King of the National Bureau of Standards, Milton

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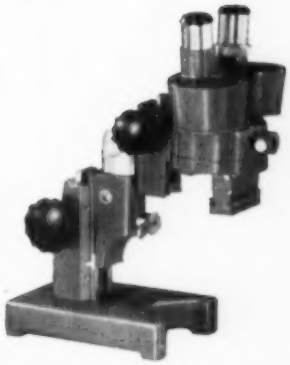

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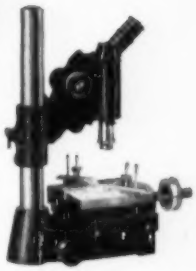

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E. Perry of Virginia Polytechnic Institute, Franklin E. Satterthwaite of Rath and Strong and Harry Romig of Hughes Aircraft. All gave somewhat different solutions.

"As you point out, the use of $d \pm \sqrt{d}$ as the control limits is not appropriate since d_i should not be considered a Poisson variate."

As both Mr. King and Mr. Perry point out, this will remove the apparent anomaly of question 1 of this problem. The second question in this problem has not been answered. This concerned the handling of demerits when the upper control limit was less than the demerit rate for critical defects. This may be more sensible in terms of a specific example.

Suppose, using Mr. King's notation, that

$$n_1 = 0.01, n_2 = 0.02, n_3 = 0.10 \text{ and } n_4 = 4$$

Then $d = 8$, and $s_d = 12.8$ with resulting control limits of 0 and 46.4. If control limits are applied to each unit, then the occurence of a critical or serious defect is bound to give a demerit weight for the unit that is above the upper control limit. The skewness of this Poisson-type distribution is obvious from the mean and standard deviation.

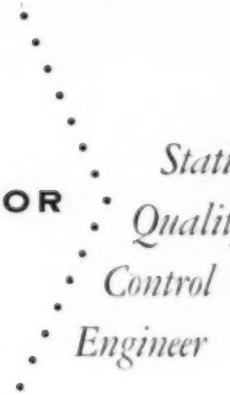
If control limits are to be kept on either the total number of demerits or the average number of demerits in $k = 100$ units, then the expected total demerits D is 800, with s_D equal 128, giving control limits of 416 and 1184. It is obvious that a critical defect in one of the hundred units need not show as above the control limit. The average demerits per unit is still 8, but the control limits for this average are now 4.16 and 11.84.

Our second question might now concern the desired value of k, the number of units. Should k always be large enough so that a critical defect *need not* show an out of control condition? If it is not reasonable to use this large a k, should not critical defects be kept separately?

Problem 6. Suggested Solution

Frank G. Norris of Wheeling Steel Corporation, Steubenville, Ohio, sends in the following comments on this problem, which concerned methods for estimating the percentage of items below a given point on a skewed distribution.

"Any method of estimating the percentage of items below a given



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value (as 0.001) depends upon the assumption that a previous distribution can (and will) be duplicated in the future, or upon the assumption that the pattern in the sample is duplicated in the large batch.

"An appropriate test of this assumption is to make a control chart for some measure of skewness. Incidentally, I think there is some tendency to overlook the generality of the method described by Shewhart as Criterion I, which is not limited to the common statistics such as X and R.

Some skewed distributions can be represented by two straight lines on normal probability paper. In other words, the long tail approximates one normal distribution, and the short tail another. In this situation, the standard deviation of the normal distribution that fits the part below the mode of the skewed distribution can be determined graphically and used as a basis of estimation. The accuracy depends somewhat on where 0.001 falls on Fig. 1 of page 102 IQC, May 1952.

"If the skewed pattern is repeated consistently, the skewedness modifies the method, but should not greatly affect the reliability of the prediction."

Bibliography

JOSEPH MOVSHIN, Editor

Assisted by the Editorial Committee, St. Louis Section, ASQC

On matters concerning the Bibliography Department, send correspondence, suggestions, and contributions to:
Mr. Joseph Movshin
9220 Old Bonhomme Road
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ANALYSIS OF VARIANCE

A NEW WAY TO GET BETTER RESULTS, SAVE MONEY IN MILL TESTING, Adrian C. Dorenfeld, University of Alabama. (Engineering and Mining Journal—v. 153, n. 10, Oct. 1952, p.78)

Factorial design is described and explained in detail. Essentially this is a method of analysis of variance to separate the effects of interaction of a series of variables. The application of this method is illustrated in detail.

APPLICATION—ELECTRICAL INDUSTRY

PAPERS ON QUALITY CONTROL.
(Transactions of the IRE—PG QC-1, Aug. 1952)

This transaction contains the following articles on the quality control of electronic equipment. Not specifically statistical quality control. Articles included are:

"Tube Reliability from the Manufacturer's Viewpoint," M. A. Acheson.

"Tube Applications for Increased Reliability," W. R. Jones.

"Discussion of the Complexity and Unreliability of Military Equipment and the Need for Simplification and Increased Life," A. S. Brown.

"Maintenance Minimization in Large Electronic Systems," W. D. McGuigan.

"The Reliability Problems in Guided Missile Development,' A. C. Packard & Royal Weller.

"Application Engineering for Improved Electronic Reliability in Guided Missiles," W. T. Sumerlin.

PRODUCTION CONTROL OF PRINTED RESISTORS, W. H. Hannahs and J. W. Eng, Sylvania Electric Products, Inc.
(Electronics—v. 25, n. 10, Oct. 1952, p. 106)

This article discusses the technical problems involved in the control of five major variables effecting the quality of printed resistors. As an aid to other engineering techniques, frequency distributions are used.

APPLICATION—MISCELLANEOUS

CASE STUDIES IN THE APPLICATION OF INDUSTRIAL STATISTICS TO PAPERMAKING, II, Charles A. Bicking and Richard T. Trelfa.
(Tappi—v. 35, n. 9, Sept. 1952, p. 413)

Two additional case studies are presented. Case VI discusses

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a method for predicting over-all paper variability from control chart calculations. Variation of paper in both cross-machine and machine direction are considered.

Case VII discusses the design of an experiment to give maximum assurance of reliability with a minimum of experimentation. An appendix showing calculations is given.

The first group of five cases was reported in the January 1952 Bibliographical Section.

QUALITY CONTROL OF LUBRICANTS, Carlyle R. Burton. (The Institute Spokesman (NL GI)—v. 16, n. 5, Aug. 1952, p. 8)

The method of controlling the quality of lubricants used by the Hibbing-Chrisholm District of the Oliver Iron Mining Company. Not SQC.

ENGINEERING AND EXPERIMENTS

NOMOGRAM FOR EVALUATING TEST DATA, Edward C. Varnum, Barber-Colman Company.
(Product Engineering—v. 24, n. 2, Feb. 1953, p. 215)

This article presents a nomogram to test the significance of the observed difference between two sample averages. The nomogram is entered with the sum of the variances of the two samples. For the number of observations in each group, a value D of difference of averages is found. Significance is indicated if the observed difference is greater than this value, D.

MANAGEMENT AND PERSONNEL, GENERAL

EVERY MAN HIS OWN INSPECTOR . . . EVERY FOREMAN HIS OWN BOSS . . . AT GRAFLEX, E. J. Tangerman, Executive Editor.
(American Machinist—v. 97, n. 3, Feb. 2, 1953, p. 95)

This report describes the philosophy and procedures employed by the Graflex Company to control quality, tooling, design, setups, etc. Emphasis is placed upon the responsibility of the individuals involved.

INDUSTRIAL MANAGEMENT

A MATHEMATICAL FOUNDATION FOR INDUSTRIAL ENGINEERING, Howard P. Emerson, University of Tennessee.
(Journ. of Ind. Eng.—v. 4, n. 1, Feb. 1953, p. 14)

Statistical mathematics, among others, is described as necessary to the industrial engineer. A table showing statistical mathematics techniques and industrial engineering applications is given. The problem of presentation of statistical mathematics is discussed.

MATHEMATICAL ASPECTS OF WORK-FACTOR ALLOWANCES FOR SIMULTANEOUS STANDARD ELEMENTS OF WORK, Dickey Dyer, Work-Factor Company.
(Journ. of Ind. Eng.—v. 4, n. 1, Feb. 1953, p. 12)

Basic theorems of probability are used to develop a mathematical procedure to calculate "simo allowances" for "variable motion sequences" in simultaneous work elements.

STATISTICS IN TIME STUDY, Dr. Robert N. Lehrer & Dr. Joseph J. Moder, Georgia Institute of Technology.
(Journ. of Ind. Eng.—v. 4, n. 1, Feb. 1953, p. 9)

This article develops a series of curves which show the number of cycles that must be observed in a time study to obtain average elements within specific limits of error. These curves are based upon the assumption of normal distributions of observed times for each elemental time considered. The calculations are of sample sizes to give averages from these distributions within given limits of the true average.

An interesting comment and critique of this article is given by John R. Huffman, University of Southern California (Page 11.)

EVALUATION IN A PROGRAM TO PROMOTE RATING ABILITY IN TIME STUDY WORK, R. O. Swalm, Syracuse University.
(Journ. of Ind. Eng.—v. 4, n. 1, Feb. 1953, p. 7)

This article discusses the use of several statistics to measure and evaluate rating ability. Correlation is considered as an improvement over older methods using measures of spreads (systematic error and mean deviation). A modified use of the root mean square deviation of the correlation between actual and rated values is developed.

MISCELLANEOUS

INDUSTRIAL UTILIZATION OF SCIENTIFIC SKILLS, Dr. David Bendel Hertz, Assistant Professor, Department of Industrial Engineering, Columbia University.

(Industrial Laboratories—v. 4, n. 1, Jan. 1953, p. 6)

This article presents results of research into the technical composition of research groups. One table shows the composition of research groups containing mathematicians and statisticians. Of 6,871 groups reported, 94 contained mathematicians, 29 contained statisticians, and 4 groups had mathematicians and statisticians combined with engineers.

INSPECTION OF TELEGRAPH MATERIAL, B. Pomerantz.

(Western Union Technical Review—v. 7, n. 1, Jan. 1953, p. 33)

This article describes the operation of the Material Inspections Division of the Western Union Company. The receiving inspection function and the methods by which various types of products are accepted is discussed.

THEORY AND APPLICATION—GENERAL

QUALITY CONTROL METHODS, Dorian Shainin, Chief Engineer, Rath & Strong, Inc., Boston, Mass.

(Part VII. "Determining Practical Tolerances," *Machine Design*—v. 25, n. 1, Jan. 1953, p. 150)

(PART VIII. "Ascertaining Machine Capability, *Machine Design*—v. 25, n. 2, Feb. 1953, p. 160).

PART VII. This article discusses the natural tolerances of a process as derived from a control chart. Nomograms for computing combinations of natural tolerances are given.

PART VIII. This article discusses the determination of process capability from the control chart. The spread of individual values and the effects of measurement errors and assignable causes are considered. Determining process capability from attribute charts is also considered.

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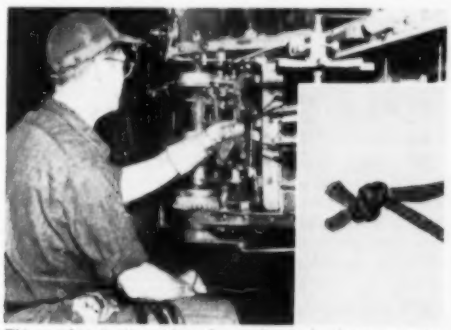

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(Factory Manag. and Maint.—v. 111, n. 2, Feb. 1953, p. 92)

The Timken Roller Bearing Company statistical quality control demonstration devices are illustrated and described. These include the bead box sampling demonstrator, the assembly tolerance demonstrator, 100 percent inspection machine, the quincunx, and the dice board as a control chart demonstrator.

STATISTICS

SOME NEW DESIGNS OF LATIN SQUARE TYPE, S. C. Pearce.
(Royal Statistical Society, Journal, B—v. 14, n. 1, 1952, p. 101)

DESIGN AND ANALYSIS OF BLOCK EXPERIMENTS, K. D. Tocher.

(Royal Statistical Society, Journal, B—v. 14, n. 1, 1952, p. 45)

REPORTED—NOT REVIEWED

T-TEST TECHNIQUES, T. R. Bainbridge.
(Modern Textiles, v. 33, Oct. 1952, p. 35)

ON THE PROBABILITY FUNCTION IN A NORMAL MULTIVARIATE DISTRIBUTION, R. S. Varma.
(Quarterly Journal Mechanics & Applied Mathematics—v. 5, Sept. 1952, p. 361)

CONFIDENCE INTERVAL FOR THE PROBABILITY THAT A NORMALLY DISTRIBUTED VARIABLE EXCEEDS A GIVEN VALUE, BASED ON THE MEAN AND THE MEAN RANGE OF A NUMBER OF SAMPLES, T. J. Terpstra.
(Applied Scientific Research, Section A—v. 3, n. 4, 1952, p. 297)

CRITICAL STUDY OF MODERN METHODS OF STATISTICAL CONTROL—NEW CONTROL METHODS, R. Cave.
(Microtecnic—v. 6, n. 1, 1952, p. 79)

Forthcoming Courses in Statistical Quality Control

7th ANNUAL PURDUE COURSE

Purdue University will hold its seventh annual advanced course in "Quality Control by Statistical Methods", June 3-11, 1953. As in the past the course is intended for those who have had an elementary course and want to learn about some of the other statistical methods not presented in such courses.

The topics include significance tests and estimation, acceptance sampling by variables, sequential analysis, linear and multiple correlation, analysis of variance, tolerances of mating parts, and the chi-square test. The same instructional staff as in the past, will include Profs. Mason E. Wescott, Edwin G. Olds, Lloyd A. Knowler, and Cecil C. Craig, and Irving W. Burr as organizer and teacher.

Information may be obtained from Prof. Burr at Purdue University, Lafayette, Indiana.

WESTERN MICHIGAN COLLEGE

A conference on the application of statistical methods to problems of the pulp and paper industry will be held under the co-sponsorship of TAPPI and Western Michigan College, June 15-26, 1953. Its first purpose is to acquaint paper mill personnel with the applicability of statistical methods to their problems. Secondly, it is designed to give preliminary training to those individuals so that they may use statistical methods in research, in production and in quality control.

The Conference will consist partly of regular lecturers, and laboratory periods, when there will be discussed the routine of applying statistical methods to mill problems. Secondly, speakers from the industry will discuss their experience with such applications.

The program will be conducted by four regular lecturers, Prof. Geoffrey Beall of the University of Connecticut, formerly of the Institute of Paper Chemistry; Dr. Charles A. Bicking, Research and Development Division, Ordnance Department, formerly with Hercules Powder Company; Dr. Charles H. Butler and Dr. Fred Beeler, Mathematics Department, Western Michigan College. Eight evening talks by men from industry will be given. Outside speakers will include: Mr. O. H. Somers, of Western Printing & Lithographing Company, Racine, Wisconsin; Mr. Fred R. Sheldon, Buffalo Electro-Chemical Company, Buffalo, New York; Mr. R. T. Trelfa, Watervliet Paper Company, Watervliet, Michigan; and Mr. B. E. Sooy, the Gardner Board and Carton Company, Middletown, Ohio.

The conference is, essentially, planned for men with university degrees. It will be given only if thirty-five enroll, but not more than fifty will be accepted, in either the first week (elementary) or the second week (more advanced) sections.

Those wishing to attend may regiser for either week, with a fee of $100, or for both weeks, with a fee of $200. Fees include room and board. For further information write to Prof. Charles H. Butler, Western Michigan College, Kalamazoo, Michigan.

UNIVERSITY OF COLORADO

A ten-day course in basic SQC will be offered by the College of Engineering (including the Departments of Applied Mathematics and Mechanical Engineering) at the University of Colorado, Boulder, Colorado, June 16-26, 1953, inclusive.

This will be a basic course covering control charts and acceptance sampling and other statistical techniques useful to industry and business. The course will be intensive, mathematically non-technical, and practical. It will be the fourth such course given by the university.

Tuition is $100, which includes books and supplies. Living accommodations will be available in modern university housing facilities, including meals, or rooms and cabins may be obtained in hotels and tourist camps off the campus.

Further inquiries and applications should be addressed to Prof. John F. Wagner, Department of Applied Mathematics, University of Colorado, Boulder, Colorado.

UNIVERSITY OF MICHIGAN

The University of Michigan has scheduled the sixth annual presentation of its ten-day intensive course in statistical quality control for Aug. 17-27, 1953, on the campus in Ann Arbor. This is a first course for executives and supervisory personnel; it is practical and mathematically non-technical. It includes the

standard control charts and sampling acceptance plans together with other basic techniques.

Instruction includes lectures, demonstrations, practice sessions, and conferences. The same experienced staff will be in charge of the course. The fee will be $100.

Please address inquiries to the course director, Prof. C. C. Craig, 106 Rackham Building, Ann Arbor, Michigan.

FOURTH "HORSE'S MOUTH" COURSE

On the basis of the experience gained and the success enjoyed by the course offered during the summers of 1950–1952, the six New England sections of ASQC are again cooperating with the University of Connecticut to present a fourth annual "Horse's Mouth" SQC Institute at Storrs, Connecticut, Aug. 23–Sept. 4.

The unique feature of this program is the diversity and prominence of the lecturers. The student is brought face to face with leaders in the quality control field who are actually applying quality control to obtain day-to-day results. The sponsors are aiming this course at those who want to look at quality control from the broad viewpoint of specific application.

Staff will again consist of nationally known people in the quality control field. Material will include detailed descriptions of the most recently developed practical techniques such as Binomial Probability Paper, Lot Plot, Continuous Lot Plot, and Reset-Run Cards.

Tuition is $160 per person and includes room, board, and text and class material. A get-acquainted cocktail party opens the Institute Sunday evening, Aug. 23, and certificates are awarded Friday noon, Sept. 4.

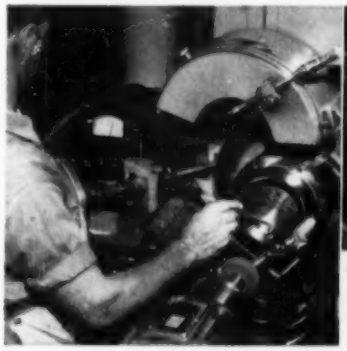
For further information or registration, write to Mr. R. M. Story, Jr., Coordinator, SQC Institute, Box U-41, University of Connecticut, Storrs, Connecticut.

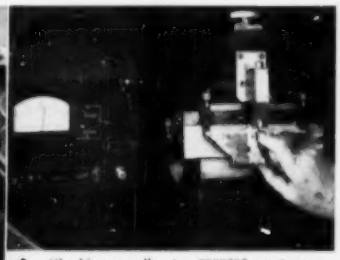
RUTGERS UNIVERSITY

An eight-day, Advanced Course in Quality Control by Statistical Methods will be offered by Rutgers University at Newark, New Jersey, Sept. 9–16, 1953. This will be an intensive course designed as a follow-up to the Basic Conference Series, but running for eight consecutive days (Sundays excepted) instead of one day a week for 10 weeks as has been the practice in the Basic Conference Series.

The course is designed to provide additional instruction for persons who have had a basic course and industrial experience in the SQC field. It will include advanced topics in SQC such as sampling by variables, sequential analysis (both attributes and measurements), narrow-limit gaging, significance of differences, tolerance combinations, simple and multiple regression and correlation, chi-square, basic experimental design, analysis of variance, and the organization and management of a quality control program.

Tuition is $150, which includes text and instructional material. For additional information write to Prof. Ellis R. Ott or Mason E. Wescott, University College, Rutgers University, New Brunswick, New Jersey.





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- in final inspection of all assembled bearings, for flatness or parallelism and for runout—both within .000075".

Par-Ac Production Gage heads and amplifiers are used

- at the machines in production inspection of rollers after grinding, for diameter, taper, and out-of-round within .000020".
- in 100% final inspection of rollers as above—and for sorting the rollers by diameter in increments of .000020".

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8TH SQC COURSE FOR THE CHEMICAL INDUSTRIES

An eight-day intensive training course in quality control for the chemical industries will be offered by the Rochester Institute of Technology at Rochester, New York, Oct. 13–21, 1953. In contrast to courses which usually emphasize mechanical and metal cutting operations, the content of this program is devoted exclusively to the control problems of the chemical and allied process industries.

The course is particularly designed for those responsible for controlling product either in the analytical laboratory or directly in the manufacturing process. Emphasis will be placed on the practical application of quality control in these areas. Instruction will cover basic statistical control and sampling methods as well as many of the advanced techniques such as design of experiments, correlation, and analysis of variance. Companies engaged in research and development work, or those having a continuous or batch-lot type of production process will find the program of particular value.

The tuition of $100 per person includes books and supplies. Room accommodations will be available at the Hotel Rochester. Further inquiries should be addressed to the course coordinator, Alfred L. Davis, Rochester Institute of Technology, Rochester 8, New York.

STATE UNIVERSITY OF IOWA

A ten-day intensive training course in Quality Control by Statistical Methods will be offered by the State University of Iowa at Iowa City, Oct. 27–Nov. 6, 1953. This will be an introductory course which will follow the same general pattern of previous basic courses.

Instruction will be by lecture, demonstration, laboratory work, and evening question and problem discussion sessions, with the emphasis on practical interpretation throughout.

The tuition of $100 per person includes all necessary instructional materials. Room accommodations will be available at the Jefferson Hotel in Iowa City. Make room reservations directly with the hotel.

Further inquiries concerning this course should be addressed to Professor Lloyd A. Knowler, Chairman, Department of Mathematics, The State University of Iowa, Iowa City.

Index to Quality Control Advertisers

MAY, 1953

Allison Division GMC 15
Aluminum Company of America 129
American Bosch Corporation 112
B. C. Ames Company 143

Bausch & Lomb Optical Company 131-142
Bell Telephone Laboratories, Inc 13
Bender Calculator Company..... 82
R. G. Bock Engineers 1
The Bossert Company 126
Bristol Laboratories Inc..... 62
Brown & Sharpe Mfg. Company... 2
Bryant Chucking Grinder Co. 93

J. I. Case Company 6
Cleveland Instrument Co. 134-139
Collins Microflat Company 126
Continental Motors Corporation 85
Cosa Corporation 45
Cummins Engine Company, Inc. 99

Davison Chemical Corporation 64
Dearborn Motors Corporation 76
Deere & Company 51
The DeLaval Separator Company .. 101
The DoAll Company 47
Edward Don & Company 100

Eastman Kodak Company 11
Elliott Service Company 72
The Exact Weight Scale Company . 142

Federal Products Corporation .... OBC

Hudson Motor Car Company 55
Hughes Aircraft Company 133
Hunter Spring Company 78

Inland Manufacturing Company ... 128
International Business Machines Corp. 49
International Harvester Company .. 123

Johns-Manville Corporation 14
Johnson Gage Company 8
Jones & Lamson Machine Company IBC
Jones & Laughlin Steel Corporation 59

Kelsey-Hayes Wheel Company 35

Magnaflux Corporation 7
The Glenn L. Martin Company 12
The Mattatuck Mfg. Company 98
McGraw-Hill Book Company, Inc. . 135
McWane-Pacific Cast Iron Pipe Co. 127
Micrometrical Manufacturing Co. .. 146
Minneapolis-Moline 9
Minnesota Mining & Mfg. Company 63
Motorola, Inc. 122

New Departure Division GMC 35
New Holland Machine Company ... 137

Nilsson Gage Company, Inc. 91
Norton Company 5

The Ohio Rubber Company 79
Optical Gaging Products, Inc. 10
Owens-Illinois Glass Company 61

Perfect Circle Corporation 96
Pratt & Whitney 87-88-89

Republic Steel Corporation 33
Rockbestos Products Corporation .. 141

Schenley Industries, Inc. 36
George Scherr Company 132
Sheffield Corporation ..... IFC
Size Control Company 41
SKF Industries, Inc. 132

(Continued on page 142)

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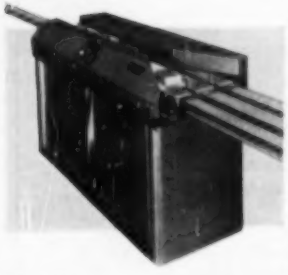

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INDEX TO ADVERTISERS (Continued)

A. O. Smith Corporation 57
Standard Gage Company 53
P. A. Sturtevant Company 137
Sylvania Electric Products Inc. 94

Taft-Peirce Manufacturing Company 37
Talon, Inc 135
Tennessee Eastman Company 119
The Timken-Detroit Axle Company 103

United Air Lines 71
U.S. Pipe & Foundry Company 120
U.S. Steel (American Steel & Wire) 117

Wamsutta Mills 105
Warner Gear Div., Borg-Warner Corp. 125
Western Electric Company 109
John Wiley & Sons Inc. 136
Willys-Overland Motors, Inc..... 111
N. A. Woodworth Company..... 121

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AMERICAN SOCIETY NEWS

NEW SECTIONS

Section No. 66 was officially recognized on Mar 11, 1953. The admission of this section represents a notable landmark in the development of ASQC—it was the Japanese Section. We want to take this opportunity to extend a warm welcome to the Japanese Section and express the hope that its affiliation with us will prove to be both useful and pleasant.

Although there are several active sections in our northern neighbor, Canada, and one in New Mexico, the Japan Section is the first to be admitted from outside of continental North America.

Officers for the Japan Section are

National Director: S. Collier, Johns-Manville Corp., New York, N.Y. (by appointment).

Chairman: Dr. Eisaburo Nishibori, Nippon Kagaku Gijutsu Renmei, Tokyo, Japan.

Vice Chairman: Dr. Shigeru Mizuno, Tokyo Institute of Technology, Tokyo, Japan.

Sec'y-Treasurer: Kenichi Koyanagi, Nippon Kagaku Gijutsu Renmei, Tokyo, Japan.

In addition to the admission of this section requests for information about how to form a new section have been received from groups in Grand Rapids, Mich., and Tucson, Ariz.

SHEWHART AND BRUMBAUGH AWARD FUNDS

A contribution of $25.00 has been received from the Dayton Section for the Brumbaugh Award Fund.

We want to express our appreciation to the Dayton Section for this contribution and also to urge that ASQC members either as individuals or acting as a section further contribute to these funds so that they may become self-supporting just as soon as possible.

To answer the questions of several individuals concerning the arrangements and goals of these funds the Executive Committee authorized the executive secretary to send a letter of explanation to the section chairmen. Since these same questions have undoubtedly been raised in your minds, the letter is reproduced here.

". . . in view of the fact that there seems to be a misapprehension about

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American Society for Quality Control

INCORPORATED 1946

This will certify that

Edward B. Haden

has been duly Elected a Fellow of the

American Society for Quality Control

an organization formed to Create, Promote and Stimulate Interest in the Advancement and Diffusion of Knowledge of the Science of Quality Control and of its Application to Industrial Processes.

Witness our hand and the seal of the Society this twenty seventh day of December 1953.

these funds on the part of some of the membership, it was agreed that this letter would be written in an attempt to clarify the situation.

"Since these two funds were established it has been our goal to make them self-sustaining; in other words, the interest from the funds should cover the expenses involved in making the respective awards. It is also desired to make the Brumbaugh Award $100.00, rather than the present $50.00. It is estimated that $4000.00 is needed to make the Brumbaugh Award self-sustaining on this basis, and that $2000.00 will make the Shewhart Medal Fund self-sustaining.

"These funds are held in a pattern similar to a trust fund and are never used for any other purposes. The Executive Committee is appealing to the Sections and individual members to help build these funds up to the goals mentioned above. When these goals are reached the funds will be closed out and a list of contributors to each will be published in the Yearbook.

"The present status of the funds is as follows:

Brumbaugh Award	$1400
Shewhart Medal	$ 580

"Therefore, we would appreciate your help and that of your respective Sections in attempting to have these funds reach the announced goals. . . ."

ASQC MEMBERSHIP CERTIFICATES

The Society now has available membership certificates for each of the three grades of membership. The individual's name will be inscribed on the certificate as illustrated in the one for Edward Haden shown in the accompanying illustration.

The cost of a certificate is $3.00 including mailing. Order direct from the national office and remit payment with the order. Samples of the certificate will be available and orders will be taken at the ASQC Booth during the convention in Philadelphia.

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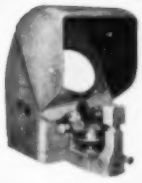
Pedestal Type
14" Diam. Screen



Bench Type
14" Diam. Screen
4 Models

Bench Type
5¾" x 7¾" Screen
3 Models

Unsurpassed Inspection Versatility

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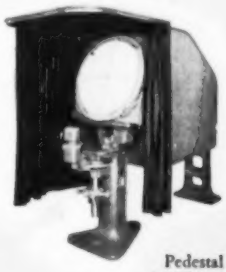
The Essence of Quality Control

Jones & Lamson Optical Comparators are designed and built like rugged machine tools to withstand vibration and hard use. Yet they have the built-in accuracy to satisfy the most exacting laboratory standards.

- **They meet** the requirements of toolroom, laboratory and production inspection.
- **They precisely measure** height, depth, lead or spacing, as well as angles to degrees and minutes. They will measure to .0001".
- **They compare** intricately contoured parts with a master outline—and measure the amount of error.
- **They are convenient** to operate, easy to set up and read direct—*without computation.*
- **They operate** under normal lighting conditions. *No darkroom is needed.*
- **They will photograph** the enlarged shadow and record its relationship to a master chart.
- **Several persons** may study the shadow *at the same time.*
- **They will inspect** and measure surface contours, as well as profiles of objects such as type faces, stamping dies, punches, worn tools, etc.

Vertical Type
14" Diam. Screen

Direct
Projection
Type



Pedestal Type
30" Diam. Screen

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Photo shows Gages for use at production and at final inspection. All these Gages were engineered directly from customer's Process Sheets and were designed from the sample parts shown and from blueprints. Each Gage checks a different dimension and is shown with its single master (not two).

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At Federal we know the basic difference between designing and building precision gages and designing other mechanical products.

Designing machines, fixtures and tools involves holding workpieces in position by *force*—transferring and transforming *power* to act as wanted—counteracting *heavy* stresses and strains.

Designing precision gages, however, requires knowledge of how to *magnify* and *transfer* measurement variations *precisely*, without *loss* of motion—with a minimum of *friction* and *inertia* in the working parts —and a hundred other details which do not concern the usual tool and machine designer.

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